DECISION SCIENCE CONSORTIUM, INC.

DECISION ANALYSIS IN FOREST SERVICE PLANNING: TREATMENT OF MOUNTAIN PINE BEETLE

Anthony N. S. Freeling

and

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Anthony N. S. Freeling

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David A. Seaver

Prepared for:

U.S. Department of Agriculture
Forest Service - Region II
11177 West 8th Avenue
P.O. Box 25127
Lakewood, Colorado 80225

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Decision Science Consortium, Inc.
7700 Leesburg Pike, Suite 421
Falls Church, Virginia 22043
(703) 790-0510

EXECUTIVE SUMMARY

This report presents the results of an analysis conducted using the methodology of decision analysis to assist the Region II Forest Service in addressing the problem of what activities to undertake in combatting the mountain pine beetle in ponderosa pine forests.

The only viable approach to reducing ponderosa pine tree losses to the mountain pine beetle is to establish a unified management effort between the Forest Service; other Federal agencies; State, County and Municiple governments; and, private land owners. All strategies (management practices) to manage the mountain pine beetle and susceptible pine stands were evaluated on their merits. The following premises were established:

1. All ponderosa pine type, regardless of ownership, was stratified into the land classification as follows:

LAND CLASSIFICATION	PONDEROSA PINE TYPE	
	M Acres	%
A. Moderate to high susceptibility Accessible High Individual Tree Value	29.1	0.4
B. Moderate to high susceptibility Accessible Low Individual Tree Value	1,178.2	15.2
C. Moderate to high susceptibility Inaccessible High Individual Tree Value	27.6	0.4
D. Moderate to high susceptibility Inaccessible Low Individual Tree Value	982.3	12.7
E. Low susceptibility Accessible High Individual Tree Value	63.2	0.8

LAND CLASSIFICATION	PONDEROSA PINE TYPE	
	M Acres	%
F. Low susceptibility Accessible Low Individual Tree Value	2,301.0	29.8
G. Low susceptibility Inaccessible High Individual Tree Value	89.4	1.2
H. Low susceptibility Inaccessible Low Individual Tree Value	3,049.0	39.5
TOTAL	7,716.8	100.0

2. Mountain pine beetle cannot be controlled by any method over extensive areas of land.

3. Control is a viable strategy in restricted areas of type having relatively high value, i.e., developed recreation sites, aesthetic areas, private land, etc. On all other lands, remove beetle infested trees as part of all timber sales.

4. The ideal strategy for managing mountain pine beetle is to intensively manage the host type, thereby preventing outbreaks from occurring.

5. Prevention is a viable strategy only in moderate to high susceptibility stands or in low susceptibility stands which will be in a moderate to high susceptible condition in the near future.

Management Opportunities identified by the Planning Question Analysis Team are:

1. Incorporate into Forest Plans management prescriptions for the major insects and diseases causing tree damage in the Region.

2. Involve State and Local governments to a greater degree in future planning efforts.

3. In cooperation with Federal, State and Local Governments and private landowners implement a management program to prevent and suppress the mountain pine beetle on all lands in land classifications A, B, C, and E (ca. 1,295.1 M acres; 16.8% of the ponderosa pine type) using the following recommended strategies.

Land Classification A - On developed recreation areas where mountain pine beetles are present, the preferred strategy is to control the beetles by harvesting beetle-infested trees. On developed recreation areas where an epidemic has run its course, the preferred strategy becomes doing nothing. If an epidemic has not yet occurred, thinning is recommended. This reduces the susceptibility of the area to mountain pine beetle.

On type A areas other than developed recreation sites, it is once again either thinning for prevention, or harvesting to control, the mountain pine beetle which out-perform all the other strategies. In areas where the beetle is already epidemic, the preferred strategy depends on how high a value is placed on the trees, and how heavy the weight is on recreational aspects. The results may be summarized by saying that if the recreational value is greater than about six times the stumpage value, then suppression is best. With lower recreation values, however, thinning is the preferred strategy. In areas where the beetles are either not present, or inactive, thinning is preferred, as thinning may prevent beetle epidemics. In particular, immediate thinning is much preferred to waiting for an epidemic to start and then thin.

Land Classification B - In these extensively managed areas a thinning program is the preferred strategy. This is due largely to the beneficial silvicultural effects and reduced detrimental recreation effects.

Land Classification C - In these areas where thinning is impractical due to constraints on accessibility and operability, suppression by chemical means is considered the best strategy under epidemic conditions. However, this strategy is only marginally superior to doing nothing and accepting the losses.

Land Classification E - On these low susceptibility areas, harvesting infested trees is the preferred strategy. Because these are high value lands, this strategy is effective in reducing the impacts on scenic, recreational and real-estate values.

In summary then, the greatest benefit appears to be from thinning programs in those highly susceptible areas where beetles are not present, but there is also some net benefit from continuing with suppression efforts in those higher value areas where beetles are present.

4. On land classification areas D, F, G, and H (ca. 6,421.7 M acres), allow the mountain pine beetle to run its course.

5. Initiate and maintain a continuous program of unified management on State and Private lands.

The procedure developed for evaluating and selecting alternative treatment strategies combines effects on various criteria (measured either objectively or using expert opinion) into a single indicator of value using subjectively assessed relative values for the criteria. In applying the procedure to this problem, using interviews with relevant interest groups, substantial differences of opinion concerning value were uncovered. However, it was found via the analysis that there was very little disagreement among interest groups with regard to the preferred treatments.

The analysis also demonstrated how the value of information that might be obtained from further study, for example, research into predicting the effects of an epidemic on a stand, can be calculated and used to guide decisions regarding the acquisition of additional information.

Other research needs identified in the course of the analysis are:

1. Conduct research to evaluate the perceived effects of mountain pine beetle on visual quality and recreation.

2. Develop a risk rating scheme for mountain pine beetle:
   a. for ponderosa pine in Colorado, and
   b. lodgepole pine in Colorado and Wyoming.

3. Conduct further study into the effectiveness of silvicultural practices in controlling mountain pine beetle.

4. Evaluate the effects of mountain pine beetle and treatments on wildlife habitat.

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1.0 INTRODUCTION

1.1 Forest Service Planning

In Region II, encompassing Colorado, large parts of Wyoming, South Dakota, Nebraska, and Kansas, the Forest Service manages 21.9 million acres of land for multiple uses, including timber, recreation, fish and wildlife, minerals, water, wilderness, and range. The required balancing of multiple uses, along with varied public interests and the long-term nature of many of the uses makes forest planning a difficult process. The passage of the Forest and Rangeland Renewable Resources Planning Act of 1974 and the National Forest Management Act of 1976 require the Forest Service to implement a systematic planning process.

In response to these planning requirements, Region II has undertaken an interdisciplinary team approach to developing a regional plan. Ten steps in the planning process have been identified.

(1) Identify public issues and management concerns and opportunities.

(2) Develop planning criteria.

(3) Identify and collect inventory data and information.

(4) Analyze management situation.

(5) Formulate alternatives.

(6) Estimate effects of alternatives.

(7) Evaluate alternatives.

(8) Select alternative.

(9) Implement plan.

(10) Monitor and evaluate plan implementation.

An interdisciplinary core team was formed to lead the planning effort. Public comments and responses to recent previous planning actions and particular

concerns expressed by Forest Service management were analyzed, and then specific planning questions were formulated to address these issues and concerns. Ten additional interdisciplinary teams were formed to analyze these planning questions. Their reports would provide the required input to the core team, to aid it in the formulation of alternative regional plans.

Decision Science Consortium, Inc. (DSC) was awarded a contract to apply decision analysis as an aid to the interdisciplinary teams addressing two of the planning questions. The decision-analytic work on Planning Question 8 addressing roads, trails and utility corridors is reported elsewhere (Seaver and Freeling, 1980). This report describes our decision-analytic efforts on Planning Question 3, which deals with the mountain pine beetle problem.

1.2 The Mountain Pine Beetle Problem

In recent years there have been major losses in the ponderosa pine forests of Region due to a renewed outbreak of an epidemic of Colorado mountain pine beetle (dendroctonus ponderosae Hopk.). Although mountain pine beetle (MPB) activity has been continuous since records have been kept (over a century), activity over the past decade has greatly increased, and there has been a widespread demand from the public for action to be taken. In response to this demand, the Forest Service developed a planning question specifically addressing the issue: "To what degree should unified management efforts be developed and implemented to suppress and prevent epidemic pine beetle infestations regardless of ownership of affected lands."

1.3 Ecology of the Pine Beetle

The adult beetle mates and flies in late summer. When beetles find a suitable tree, they bore into the bark and the female lays her eggs under the bark, in August to September. The larvae hatch and feed on the tree,

developing through the winter and spring. The real killing agent, however, is not the beetle itself but the "blue-stain fungus" that is carried by the adult beetle. This fungus blocks the tracheas of the tree, through which water is normally transported, and the tree thus dehydrates and dies. As soon as the fungus is in the tree, the tree may be considered to be dead. The externally observable symptoms are that the needles turn red in the first year, and stay red for about two years before falling. The tree will remain standing but bare until about five years after infestation, after which time it will fall. The "blue-stain fungus" colors the timber an attractive shade of blue (whence its name) which adds to the value of the timber for decoration.

There are several treatments available to combat the MPB, as discussed in Section 2.0. Each of these attempts to treat the beetle rather than the fungus. There are three chemicals of potential use--Carboryl, which is used for protecting a tree from future infestation: Lindane, which is used for spraying infested trees to prevent beetles flying to another tree: and Ethylene dibromide, which is used similarly to Lindane, but which requires a license to use. Each of these chemicals, if used according to instructions, is considered safe ecologically.

1.4 Use of Decision Analysis in Forest Service Planning

Decision analysis can support Forest Service planning in several ways. It provides a highly structured procedure for decomposing planning problems into their critical elements; and direction, and theoretical justification, for combining the elements to answer the primary questions of interest. More importantly, however, certain aspects of decision-analytic procedures are particularly responsive to Forest Service planning needs. A specific problem in Forest Service planning is the need for a balanced consideration of all resources in the planning process. That is, all commodity and amenity outputs, with both market and non-market values, must be attended to in selecting preferred plans or alternatives. Forest Service planning cannot

simply focus on maximizing the economic value of timber production, while giving only verbal qualitative attention to non-market commodities and amenities such as fish and wildlife, recreation, and aesthetics. But this means that procedures must be used to quantify the effects of Forest Service plans on these resources and to assign value to them in a manner such that tradeoffs can be determined. Decision analysis and the techniques of multi-attribute utility theory (discussed in the Appendix) provide a mechanism for quantifying these "non-quantifiable" values and tradeoffs.

Decision analysis also offers a framework within which to consider the effects of the uncertainty that is inherent in any planning process, particularly one with a 50-year time horizon, such as Forest Service regional planning. The explicit incorporation of uncertainty into the planning process not only improves planning because otherwise ignored possibilities are addressed, but also can help identify critical areas in which additional information and/or research may be valuable. Information can reduce uncertainty and reduced uncertainty can improve decisions. Decision analysis provides a formal procedure for quantifying the value of information by considering how it improves the expected value of decisions. Sensitivity analysis can also indicate areas needing additional research and more careful study, and the quantified structure of decision analysis facilitates sensitivity analysis and its interpretation.

These analytic tools of decision analysis are useful in planning, but perhaps even more useful, particularly in a public planning process such as is required of the Forest Service, is the ability of decision analysis to represent the viewpoints of various interest groups in a logical and consistent manner. The Forest Service must be responsive to the public, and by assessing the values of major interest groups through the use of decision analysis, the Forest Service can incorporate them into its planning efforts. Thus, decision analysis can communicate public values to the Forest Service, and, in turn, can communicate and justify Forest Service decisions to the public. This communication function is extremely useful given the current concern with public involvement in planning.

The efforts of the Planning Question team in addressing the MPB problem are described in the Planning Question 3 Report, which includes a summary of the decision-analytic work. In this report, we describe in depth the decision-analytic approach and the results of our analysis.

2.0 TREATMENT STRATEGIES AND LAND CLASSIFICATION

2.1 Available Strategies

The first stage of the analysis was to discover the available options for treating ponderosa pines, to suppress or prevent epidemic pine-beetle infestations. These can be viewed in two categories - those treatments aimed at preventing future epidemic infestation of pine beetles, and those treatments aiming simply to suppress (control) infestations already of epidemic proportions.

The specific techniques available are:

Preventive
- Thinning of stands
- Preventive spraying
- Favoring tree species other than ponderosa pine

Suppressive
- Direct suppression using insecticides or fire
- Logging infested trees

We now discuss briefly the nature and effect of each of these techniques.

1. Thinning - Dense, unmanaged second stands of pure or nearly pure ponderosa pine have been a factor in most of the recent MPB outbreaks in Region 2 (R-2). Thinning is the easiest method to radically change stand conditions. Under ideal conditions some monetary return from the thinned material can be obtained.

2. Preventive individual-tree spraying - During periods of severe beetle activity, trees can be sprayed to kill attacking beetles. The treatment is safe and sure, but relatively expensive since it is done on an individual-tree basis.

3. Favoring other tree species - This may be a practical approach in some instances, but has had little or no application in the still-essentially unmanaged R-2 forests.

4. Direct suppression - This approach to bark beetle "control" has a history in R-2 stretching back nearly 80 years. Techniques include insecticides and fire, and are all based on the notion of killing beetles in currently infested trees so those beetles will not be able to emerge and attack green healthy trees. Direct control is expensive, and carrying it out effectively involves a high order of organization and cooperation.

5. Logging infested trees - This accomplishes the same objective as direct suppression, i.e., removing the beetle population--or at least part of it--from the woods.

Technique number 3, favoring other tree species, was not considered to be a viable alternative to mountain pine beetle prevention. There are inherent problems in favoring tree species other than ponderosa pine on ponderosa pine sites. The few viable techniques for prevention and suppression of mountain pine beetle are coded and listed below:

P1 - Prevention through thinning,
P2 - Prevention through chemical treatment,
S1 - Suppression through logging infested trees, and
S2 - Direct suppression using chemicals, fire, etc.

All possible combinations of techniques were reviewed and evaluated. The combinations of techniques which were considered to be viable strategies for prevention and suppression of mountain pine beetle are:

Prevention and Suppression

P1S1,
P2S1,
P2S2, and
P1P2S1;

Prevention

P1,

P2, and

P1P2;

Suppression

S1, and

S2.

Only combinations of techniques that would logically be applied to a small parcel of land such as a private homesite or a forest stand were considered.

The major combinations missing from the above list are those using both P1 and S2, and those with both S1 and S2. The former were omitted because if one thins an area, one will automatically take out the infested trees, thus rendering direct suppression unnecessary. Since S2 is more expensive than S1, it was thus considered inappropriate in such areas. Since both methods of suppression perform similar effects, the planning team agreed that S2 was only an appropriate strategy when S1 was impracticable.

2.2 Land Classification

It became apparent very early in the study that the appropriate treatment for a given area of land depended strongly on the nature of that land. It was also established that, for Forest Service lands an appropriate unit over which to consider one particular strategy was a stand. This may be understood as a group of trees over a fairly large number of acres, with similar characteristics with regard to size, age, density, etc. For smaller land-owners the extent of their homesite would be a more appropriate unit.

The stand characteristics affecting potentially available strategies were considered to be:

- The susceptibility to epidemic MPB infestations,
- the accessibility of the stand for logging or thinning operations,

- the extensiveness of lands surrounding the stand, with similar characteristics, and
- the overall value of the stand, taking into account the non-market aspects.

We now discuss briefly the effects changes in the above characteristics have on the available strategies.

1. Susceptibility - The amount of effort that is worthwhile putting into controlling the MPB in a given stand is clearly dependent upon the likelihood of an epidemic occurring. This likelihood can be summarized by rating the stands susceptibility. Research indicates that such susceptibility arises from having dense, overstocked stands, resulting in weaker trees, and from stands being single-storied, allowing the MPB to fly easily from tree to tree.

2. Accessibility - In order to use strategies S1 or P1, the stands must be accessible and operable, so that felled trees can easily be removed from the sites. In stands which are inaccessible we are restricted to S2 and/or P2.

3. Extent - Many areas of Forest Service lands can only be managed extensively, i.e., areas of several thousand acres may have similar characteristics and the entire area may have to be considered as a single entity. However, no strategy combating MPB could possibly be used over the entire area at once due to its size. This means that suppression is ruled out as a sensible option, for two reasons. First, one can never know exactly where MPB is epidemic, with such a large area to search; and second, if a suppression program is set up in one small area, the MPB will simply fly elsewhere in the stand, thus starting a chase which humans could never win. It was therefore agreed by the PQ team that in such areas the decision was simply whether to employ silvicultural treatments (thin) or not, with the understanding that if MPB was encountered, infested trees would be harvested.

4. Value - The overall value of an acre of land would be the deciding factor on whether the cost of a treatment was worthwhile or not. Such value arises from the "non-market" aspects of the trees; mainly the impacts they have on recreation, on visual beauty and real estate value. Since people derive pleasure (or money) from these impacts the trees have an importance over and above their stumpage value. Therefore, for example, trees in or around developed recreation sites may be worth saving more than ones in the middle of a timber purchase. In particular the expensive treatments such as P2, could only possibly make sense for trees of very high individual value.

Based on the above observations the land in Region 2 was classified, as shown in Exhibit 2-1, into eight regions. We now give the rationales for this classification.

1. Degree of susceptibility - The degree of ponderosa pine susceptibility can be evaluated on units no larger than a stand (Stevens, McCambridge, and Edminster, 1980). No risk rating guide exists for ponderosa pine outside of the Black Hills. Since stand data and rating guides for the entire Region are not available to risk rate individual stands, an estimate of susceptibility was obtained independently from four individual entomologists in the Region. The estimated susceptibilities by State are:

	% Susceptible Type	
	Moderate to High	Low
Colorado	30	70
Wyoming	40	60
South Dakota	55	45

2. Access and Operability - Access and operability were estimated from timber land use summaries. Estimates were based on the percent of timber in the Standard and Special components on NFS lands. It was

LAND CLASSIFICATION	PONDEROSA PINE TYPE	
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EXHIBIT 2-1

Classification of Land Types

assumed that these estimates would be similar for State and Private Forest (S & PF) lands. These estimates by State are:

	% Type	
	Accessible	Inaccessible
Colorado	35	65
Wyoming	44	56
South Dakota	90	10

3. Tree value - For the initial classification, high and low tree values were considered. The high value was for intensively managed lands, particularly privately owned lands, developed recreation sites, etc. The low tree value was for extensively managed lands with a non-market value not greater than the market value of current stumpage value. Both values, initially, were qualitative.

4. Using the three criteria the eight land classifications were developed. The total acreage of ponderosa pine type was divided by ownership and use to reflect areas of high and low value. All privately owned lands, other than forest industry, and high use public recreation areas, including Federal, State, county and municipal, were assigned to the high value category. All other lands were assigned to the low value category. These areas were then divided by straight percentages into susceptibility and accessibility classes. For further details of the sources of information used in this classification, see the report of the PQ3 team.[1]

It should be noted that some of the areas with low susceptibility were in this category due to having younger trees, less densely distributed. Over time, these characteristics would change and that stand would then move

[1] In Exhibit 2-1, the percentage of lands falling into the high value area is small and reflects lands which are essentially of a developed nature. There are, however, many National Forest lands which may be fairly intensively managed, and of high overall recreational and scenic value, while not being of as high value as developed sites. Although such areas are classified under "Low value," they are in fact considered in the analysis as having all the strategies that are available in "High value" lands, open for them. This point is further discussed in Section 5.0.

into the high susceptiblity category. It was agreed that in such areas preventive action need not be considered until the stands had reached the borderline on susceptibility.

2.3 Restriction of Options in Each Land Area

In this section we look at the options we considered as being viable in each of the areas A-H, and give the rationale for such a selection.

Land Type:

A. These areas are those which are simultaneously at most risk, of greatest concern to us, and easily operable. In such a situation all the options are potentially viable, and all were analyzed, so that their effects could be explicitly shown (even though, a priori, some options would clearly not be preferred).

B. In these extensively managed areas, as noted in 2.2, it is not possible to suppress effectively nor is spraying of every individual tree a viable option. The only viable option is thus thinning for prevention; harvesting infested trees as encountered.

C. Because the area is inaccessible to current logging techniques, P1 and S1 are not viable strategies. The viable strategies then become P2, S2 and P2S2.

D. Because of the extensive area covered and inaccessibility, there are no viable strategies.

E. These are areas where the Forest Service would not wish to lose significant numbers of trees, and would be able to perform any of the potential treatments, but where we also do not expect to lose many trees in any case. For this reason there was not considered to be any point in preventive techniques, as they would not appreciably change the stand risk-rating. (As noted in 2.2 such stands

might eventually grow into category A, at which time the action in the stand would need to be re-evaluated). A low proportion of such stands may already have beetles in epidemic form, and on these areas S1 is a viable option (S2 was not considered as it would have the same effect as, at greater cost than, S1).

F-H For reasons stated under E (above) P1 and P2 are not viable strategies. S1 and S2 are not viable strategies for F and H because of the extensive area covered. S1 and S2 were not considered viable strategies for G because widely scattered infested trees occurring in inaccessible areas would render costs prohibitive. Therefore, there are no viable strategies for these areas.

It will be noted that in areas D, F, G, and H, we have already declared that we must simply let the beetle epidemic run its course. Such lands, at the most conservative estimate, consist of 75% of the ponderosa pine type in the region. By classifying the lands in the manner described, we have thus already lessened the scope of the problem and focused our attention on the real problem areas.

One further fact was needed before the available options could be finally delineated. This concerned the question of whether the MPB was or was not already present in epidemic form in the stand. This is important because suppression techniques are clearly only possible if there is something to suppress. The way this was modeled in discussed in Section 3.0.

3.0 UNCERTAINTIES

The next stage in modeling the decision was to identify the critical uncertainties, to discover where, when, and how they impact the decision, and to elicit probabilities of the differing outcomes.

The areas of uncertainty that were initially identified by the PQ team as being of potential importance concerned the probability of an epidemic occurring in a given stand-type, the effect of an epidemic MPB infestation on a stand, the effectiveness of the various treatments in combating the MPB, the degree of cooperation the Forest Service could expect from other landowners in carrying out a recommended treatment, and the possibility of further action after undertaking preventive spraying (P2). In this section we discuss the way in which each of these areas of uncertainty was handled in the decision analysis.

3.1 Analysis of Severity of Epidemic

3.1.1 Moderate to high susceptibility stands. The Forest Service definition of epidemic was used throughout this study. This uses the criteria that MPB is epidemic if, and only if, at least two trees/acre are infested at a given time. If there are fewer trees infected, i.e., a few beetle-killed trees scattered throughout a stand, the infestation is considered endemic. It is expected that MPB would be present in endemic density throughout most of the ponderosa pine type stands, and prevention or control could only be effective to the extent of reducing epidemic populations to endemic ones. The occasional tree killed due to endemic beetle was ignored, on the grounds that this would not have significant impact, and because the effect would not vary across options in any case.

The PQ team agreed that the possible range of effects of the MPB in a moderate to high susceptibility stand could be captured by considering the stand to

be capable of being in one of three possible conditions given that an epidemic had started in the stand. It could lead to:

- a "typical" epidemic in terms of beetle kill, which we term "mild", or
- a heavy epidemic, with far more extensive tree-kill, or
- the epidemic might stop before running its full course, due usually to inclement weather conditions in the winter.

We now examine what is meant by each of these three conditions. A mild infestation is the type of epidemic that would occur in the great majority of those stands suffering from an epidemic outbreak. The PQ team agreed that, if left to run its natural course, the epidemic would last for about five years before dying out (or moving on to another stand). The reason that the epidemic dies out is that the MPB will tend to attack those trees that, for some reason or other are more susceptible to attack. After about five years the MPB will have eliminated these higher susceptibility trees, and will, of its own accord, have changed a high-susceptibility stand to a lower one.

In this mild epidemic the beetle tends to kill groups of trees over the five year period, rather than trees uniformly distributed throughout the stand. These groups, which we assumed to be totally destroyed, are typically of about 1000 trees in size, and of sufficient density to account for one quarter of the total number of pines in the stand. The remaining three quarters of the stand would be substantially unharmed. A heavy infestation would occur in a small proportion of stands where the MPB will have a far more devastating impact, destroying almost the entire stand. Once again, such an epidemic lasts for only about five years. At present we are unable to predict in advance whether an infestation will be of the mild or heavy type, though of course we would know this after the fact. The importance of this is discussed later in this section.

On some occassions when an epidemic breaks out in a stand, it will die out naturally within two years, before attacking many trees. This was termed a "stopped epidemic." Such a stop will often be due to a cold winter, but there appear to be other reasons, which are as yet not fully understood. In this case,

the stand remains highly susceptible to a new epidemic outbreak, since an endemic beetle population will still be present in the stand.

3.1.2 Low-susceptibility stands. The low susceptibility stands are naturally considered less likely to support a MPB epidemic. However, the occurrence of such an epidemic was not ruled out in these stands. Due to the reduced susceptibility, however, the outbreak would have less effect, killing fewer trees.

3.2 Incorporation of Uncertainty about Epidemic Severity into the Decision Tree

The probabilities of the various types of epidemic in the different lands were given by the PQ team. In moderately to highly susceptible areas, they stated that only 15% of the stands could be expected to be substantially free of beetles at a given time. Sixty-eight percent of the area would suffer a mild epidemic, about 4-1/2% a heavy one, and the remaining 12-1/2% of the time the epidemic would stop, making up the remaining 85%. It was assumed that in the intensive, high-value, lands (A and C) we would know before deciding upon our action whether the beetle was active, inactive, or had not been in the stand (i.e., whether the stand was in the state of Mild/Heavy, stopped, or No Beetles). However, we would not yet be able to tell whether a current infestation would be mild or heavy. This was modeled (see Exhibit 3-1) in the decision tree by placing the probability node specifying Mild/Heavy, Stop, or None before the decision nodes for these types of lands, but the node describing whether the epidemic was in fact mild or heavy, after the decision node.[2]

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[2] It will be noted that there are, in fact, four distinct trees in Figure 1, one each for lands A, B, C, and E. A square node represents a decision, the others probabilities. The tree should be read from left to right, with the final outcome at the far right. So, for example, the top branch describes the situation in Lands A, where we know a mild or heavy epidemic is underway, we decide to take no action, and then discover that the epidemic, in fact, turns out to be a mild one. The numbers after each probability node are the probabilies of moving out that branch. To arrive at the overall probability of that branch, one must multiply all the probabilities on it. So for the top branch, the overall probability is .725 x .94 = .68, agreeing with the 68% probability of a mild infestation discussed above.

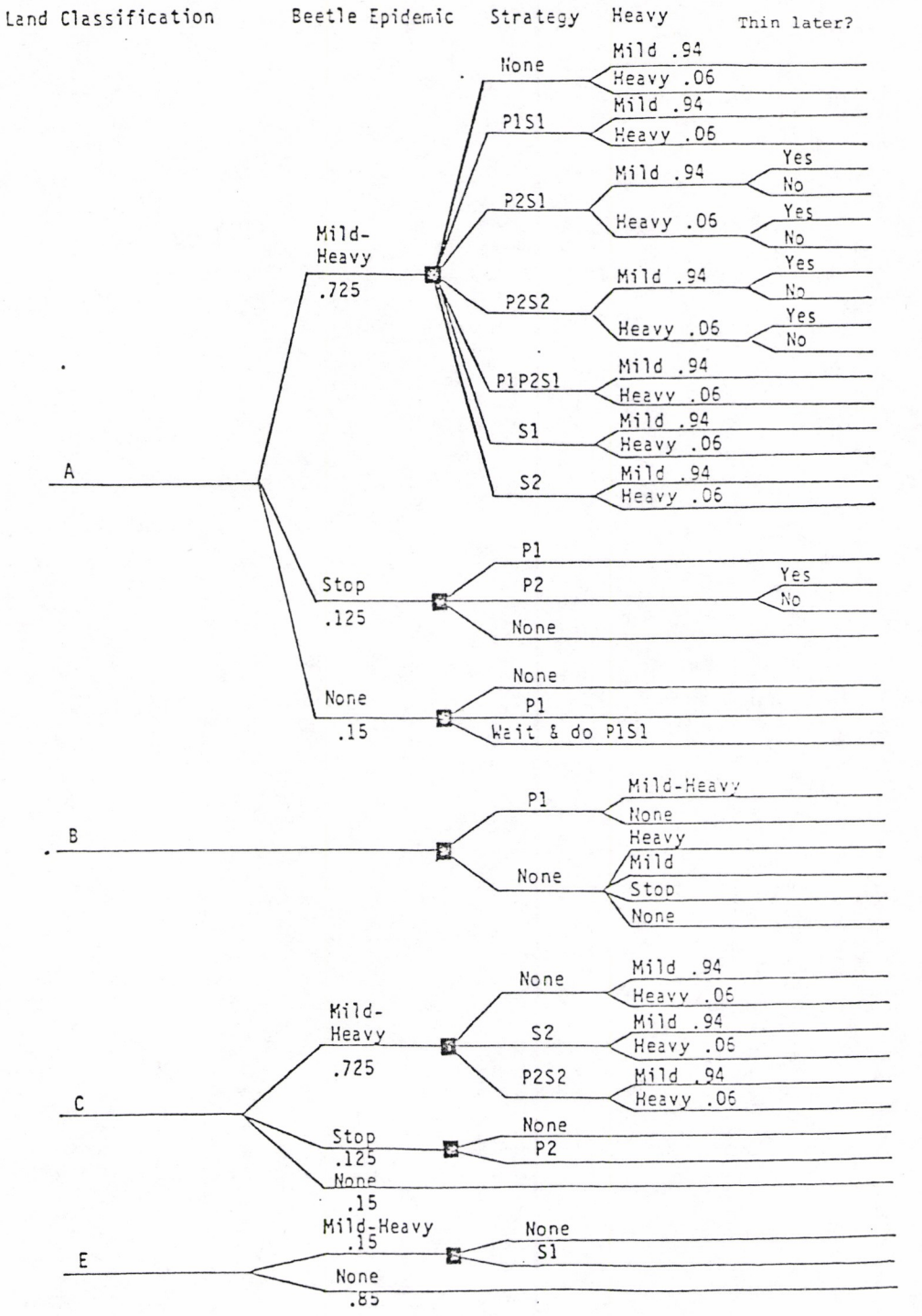


EXHIBIT 3-1

Decision Tree Used in Decision Analysis of Mountain Pine Beetle

It will further be noted that the type of epidemic known to be in the lands restricts the viable treatment strategies. In lands A, all strategies are possible if an epidemic is in progress. However, if the epidemic has stopped, suppression techniques are pointless, so only prevention is viable. Where there are no beetles as yet, the PQ team decided to compare only the options of doing nothing, of thinning now, and of waiting until an epidemic started and then thinning.

In lands C, it was agreed that, due to inaccessibility the Forest Service would do nothing if there were no beetles in epidemic proportions, P1 being impractical, and P2 too expensive. In lands B, due to the extensive area, it was assumed that the status of the beetles would not be known in a particular stand, and hence that the decision to thin or not would be made prior to discovering the form of the epidemic. This is shown in the decision tree by placing the decision node first. Further, since P1 is assumed to reduce the stand to low susceptibility, after this action we are only concerned whether beetles are active or not. This is further discussed in Section 3.5.

In the low susceptibility areas, the PQ team stated that at any given time, about 15% of stands would be supporting an epidemic. All such epidemics would be of a fairly mild type and it was considered unnecessary to further distinguish among types of epidemics in these areas.

3.3 Further Action: Thinning After Preventive Spraying

The PQ team opined that, except in very rare cases, it would never be economically feasible to use preventive spraying, unless one expected to thin in the near future. There might be various possible reasons preventing immediate thinning, and one could not be certain whether one would in fact be able to thin in the future. This uncertainty (which was only relevant in lands A) was modeled by including a probability node after those options including P2. The probability of thinning later would clearly vary in different cases, so this is left blank in Exhibit 3-1. In the analysis, this was dealt with by using a sensitivity analysis, which is equivalent to trying all probabilities for these nodes.

We have now discussed all the steps that went into structuring the decision tree, as it is shown in Exhibit 3-1. We now continue by discussing the way uncertainty concerning the effects of epidemics and of treatments, and uncertainty regarding cooperation, was handled in the decision analysis.

3.4 Analysis of Effectiveness of Treatments

3.4.1 Typical stands. In order to quantify the effects of MPB on stands, it was decided to use a "typical" moderate-to-high susceptibility stand and a "typical" low susceptibility one. The PQ team agreed to take the moderate to high stand as being of 150 acres, with 150 trees/acre, all of 12 inches d.b.h. (diameter breast height). This is, of course, highly idealized, but captures the essential characteristics of such stands.

A low susceptibility stand was assumed to vary solely in terms of the tree density, which was taken as 75 trees/acre. It was further assumed that thinning would change a typical moderate-to-high susceptibility stand into a low susceptibility one, by removing half the trees.

A time horizon of 20 years was used throughout this study, as no treatment or epidemic will last or have an impact beyond this time-horizon; for example, a thinned stand would grow again and reentry be required after about 20 years.

3.4.2 Beetle dynamics. In order to evaluate the effect of the MPB on stands, a simple model of beetle dynamics was used. The reason that epidemics spread is that beetles in an infested tree fly to nearby trees and infest some of these. A measure of the rate of spread is the "hit-rate," which is defined as the ratio of the number of newly-infested trees in one year to the number of trees infested during the past year. This hit rate, at the height of an epidemic is usually around 2 to 3. However, it occassionally reaches 10, or even higher. Such cases are the ones that lead to heavy epidemics. The hit rate drops as the number of susceptible trees in a stand decreases, and since this occurs naturally as the epidemic proceeds, the hit rate drops below one, and the epidemic stops in that stand. It was assumed that in the natural situation, the epidemic would last for five years.

Time streams of tree-kills were developed for each type of stand under each feasible treatment strategy, (see Exhibits 3-2 through 3-5). We now proceed to explain the rationales for these numbers. (For explanation of the columns whose headings include "% COOP", see Section 3.5.)

3.4.3 No treatment. In moderate-to-high susceptibility stands, a mild epidemic was assumed to have a maximum hit rate of three. It was further assumed that the beetle kills could be concentrated on groups of trees of about 1000 trees each. The PQ team estimated that five such groups could be expected in the typical 150 acre stand. These imply a total kill over the stand of about one quarter of the trees. The numbers in Exhibit 3-2 all refer to such epidemics, and numbers are newly killed trees/group.

In the same stands, a heavy epidemic was assumed to have a maximum hit rate of ten. In these stands, we would expect the loss of over 95% of the trees, and for simplicity we treated such a kill as being of all the trees in the stand.

In those moderate-to-high susceptibility stands where beetles were not at present active in epidemic proportions, the PQ team estimated that an epidemic would begin after a two year wait. This relatively short time reflects the high susceptibility of these stands. For such new outbreaks, it was assumed that they were of the "mild" variety. This reduced the amount of computation required in the analysis, and is quantitatively a good approximation to a more complete analysis, whereby this new outbreak could be of any form. So for the "stopped" areas, the beetle kill was assumed to be in five groups of 1000 trees each, with the first year kill as with the "mild" infestation; then a greatly reduced kill for the next year, after which time the hit rate rose once again, with the total number of trees killed the same as with the mild infestation. For those areas without beetles, the time flow was taken to be the same as for a mild infestation with a delay of two years.

In low susceptibility areas, there was likely to be a considerable wait before beetles attacked an area at present free of them, and in any case, there was little point in preventive measures in such areas. Hence, we only analyzed low susceptibility areas with beetles present. In such areas the low susceptibility would lead to a low hit rate--we assumed a maximum of two--and very

STANDS OF 150 ACRES; 150 TREE/ACRE; 5GPS, OF 1,000 TREES EACH, DYING PER STAND

MORTALITY RATES ARE TREES/GROUP OF 1,000 TREES

YEAR	NONE	TREATMENT						
		S1 or S2 100% COOP	S1 90% COOP	S2 75% COOP	P1S1	P2S1 or P2S2; No Thin Later	P2S1 or P2S2 Thin Later	P1P2S1
1	80	80	80	80	80	80	80	80
2	240	*240[1/]	*240	*240	*240	*240	*240	*240
3	480	70	120	300	30	* 0	* 0	0
4	160	*140	*240	*200	20	* 0	* 0[2/]	0
5	40	20	80	120	20	80	C	0
6	0	*30	*120	40	10	240	0	0
7	0	5	30	20	5	200	0	0
8	0	15	60	0	0	100	0	0
9	0	10	30	0	0	60	0	0
10	0	0	0	0	0	0	0	0
TOTAL	1,000	610	1,000	1,000	405	1,000	320	320

[1/] Asterisks denote years in which treatment performed

[2/] In this year both thinning and preventive spraying carried out

EXHIBIT 3-2

Mortality Rates in Moderate-to-High Susceptibility Stands with a Mild Epidemic

few beetle-killed trees. The PQ team estimated that over the 20 year time horizon, in the typical stand, a maximum of 5% of the trees could be expected to be killed, in groups of ten to fifteen trees.

3.4.4 Suppression techniques. The method by which S1 or S2 suppress the MPB is removing beetles from a threatened area. This is achieved either by physical removal (S1) or by killing the beetles in trees that have already been infested. Ideally either of these techniques would remove all of the beetles, but for practical reasons this does not happen. The PQ team estimated that in reality, under both S1 and S2, about 15% of the trees would be missed, except that in inaccessible areas, where S2 was carried out, the added difficulty would mean that about 20% of the trees would be missed. We assumed that the hit rate would remain the same after suppression as before, and hence that the epidemic would start to build up again. It was thus assumed that with mild epidemics, we would suppress three times, and with heavy epidemics, four times. With this frequency of suppression, there would always be sufficient trees infested for suppression to be economically feasible. Even so, as can be seen in Exhibits 3-2 and 3-3, such treatment has only a delaying effect on the epidemic; it does not halt it. (Except for reduction in total kill with mild and 100% cooperation).

3.4.5 Thinning. Thinning was assumed to take a stand to low susceptibility. This was assumed to mean that, in areas where there was no epidemic present at the time of thinning, there would remain no epidemic over the twenty year time horizon. In areas where an epidemic was current, it was assumed that the hit rate would drop to one and then drop further. Since it was always assumed that S1 would accompany P1, the number of infested trees available to spread the epidemic was assumed to be reduced to the number missed by harvesting. Re-entry would be required every 20 years if the stand was to remain of low susceptibility.

3.4.6 Chemical prevention. Chemical prevention (P2) was assumed to be 100% effective, i.e., any tree sprayed would be immune to the MPB for a year. After this time, however, the tree would be back to its pre-treatment susceptibility. Furthermore, since all trees in a stand would need spraying, rather than a selection, it was assumed that none would be missed. Because of the short-lived effect of this treatment, it would require re-entry to be made each year. Because of the extremely high cost of the treatment, it would not be economi-

STANDS OF 150 ACRES; 150 TREES/ACRE

MORTALITY RATES ARE TREES/ACRE

YEAR	NONE	TREATMENT						
		S1 or S2 100% COOP	S1 90% COOP	S2 75% COOP	P1S1	P2S1 or P2S2 Thin Later	P2S1 or P2S2 No Thin Later	P1P2S1
1	2	2	2	2	2	2	2	2
2	10	* 10[1/]	* 10	* 10	* 10	* 10	* 10	* 10
3	100	* 15	* 20	* 30	2	* 0	* 0	0
4	25	* 20	* 40	* 80	1	* 0[2/]	* 0	0
5	10	* 30	* 50	20	0	0	0	0
6	3	40	20	8	0	0	2	0
7	0	25	8	0	0	0	10	0
8	0	8	8	0	0	0	90	0
9	0	0	8	0	0	0	30	0
10	0	0	8	0	0	0	6	0
11	0	0	8	0	0	0	0	0
TOTAL	150	150	150	150	15	12	150	12

[1/] Asterisks denote years in which treatment performed

[2/] In this year both thinning and preventive spraying carried out

EXHIBIT 3-3

Mortality Rates in Moderate-to-High Susceptibility Stands with a Heavy Epidemic

STANDS OF 150 ACRES; 150 TREE/ACRE;

5 GROUPS, OF 1,000 TREES EACH, DYING PER STAND

MORTALITY RATES ARE TREES/GROUP OF 1,000 TREES

	TREATMENT			
Year	None	P1	P2 No Thin Later	P2 Thin
1	80 [1/]	80	80	80
2	*12	*12	*12	*12
3	40	15	* 0	* 0 [2/]
4	90	12	* 0	* 0
5	180	6	0	0
6	350	0	70	0
7	150	0	210	0
8	50	0	420	0
9	35	0	150	0
10	13	0	40	0
11	0	0	18	0
TOTAL	1000	125	1000	92

1/ Asterisks denote years in which treatment performed

2/ In this year both thinning and preventive spraying carried out

EXHIBIT 3-4

Mortality Rates in Moderate to High Susceptibility Stands With a "Stopped" Epidemic

STANDS OF 150 ACRES; 150 TREE/ACRE;
5 GROUPS, OF 1,000 TREES EACH, DYING PER STAND
MORTALITY RATES ARE TREES/GROUP of 1,000 TREES

	TREATMENT		
Year	None	P1 1/	Wait for Beetles (P1S1)
1	0	*0	0
2	0	0	0
3	80	0	80
4	240	0	*240
5	480	0	36
6	160	0	20
7	40	0	20
8	0	0	10
9	0	0	5
10	0	0	0
TOTAL	1000	0	411

1/ Asterisks show year in which treatment was performed

EXHIBIT 3-5

Mortality Rates in Moderate to High Susceptibility
Stands With Beetles not Epidemic

cally viable to continue such treatment for more than three years, after which time the stand sould be once again of its natural susceptibility, although without epidemic beetles. Therefore, there would be a delay of two years before a mild epidemic broke out (in the moderate-to-high susceptibility stands). It was suggested (as mentioned earlier) that P2 would only be carried out in such cases if one hoped to thin later, but for some reason such thinning was impossible at the present time. If such thinning was in fact carried out at the end of the three year period, we assumed that no further trees were lost.

The alternative P1P2S1 was perhaps the ideal use of chemical prevention; in this case the spraying is to prevent any more trees dying (after the unavoidable first two years). We thus assumed a zero tree kill after the second year, which meant the lowest overall tree kill.

3.5 Cooperation

In order to perform the analysis it was necessary to take account of the degree of cooperation the Forest Service might expect to get from other land owners, and to estimate the effect any lack of cooperation might have on the efficacy of the treatments. In the case of suppression, lack of cooperation from owners of contiguous lands could result in more beetle infested trees remaining in the vicinity than would otherwise be the case. These trees could then keep the epidemic going, even in the absence of infested trees on Forest Service land. A quantitative estimate of the impact of such cooperation was made by eliciting assessments from the PQ3 team of the total percentage of trees that they would expect to be treated in the recommended way under each alternative for each type of land. These assessments are shown in Exhibit 3-6. In the case of S1 or S2, they were used to derive time-streams of trees lost by assuming the total percentage of infested trees left to be 100-xy, where x was the percentage cooperation, and y the percentage of infested trees that would be removed where suppression was carried out. So, in lands Type A under S1 with full cooperation, x = 100, y = 85, and hence 15% of the infested of the infested trees remain. With the anticipated 90% cooperation, x = 90, y = 85, and 23½% of the infested trees remain. The hit rate was assumed to remain the same as before, and from this data the time stream was calculated. As will be observed from the exhibits, with cooperation below 80%, there was almost no impact of suppression.

	LAND TYPE			
OPTION	A	B	C	E
P1S1	75 [1/]	60 [1/]	N/A	N/A
P2S1	85	N/A	N/A	N/A
P2S2	70	N/A	15	N/A
P1P2S1	55	N/A	N/A	N/A
S1	90	N/A	N/A	90
S2	75	N/A	60	N/A
P1	60 [1/]	N/A	N/A	N/A

[1/] The figure for P1S1 in lands A is where the beetle is epidemic, and for P1 where it is not. In lands B, P1S1 is being used to represent a thinning program, where we do not know if beetles are epidemic. In the other lands we only consider action where the beetle is epidemic, so no problem arises.

EXHIBIT 3-6

Anticipated Cooperation (in percentage)

Lack of cooperation in thinning was assumed not to change the effectiveness of thinning on Forest Service lands; the shift to low susceptibility would still occur. The only change would be in a slightly increased number of infested trees remaining after treatment, but this was considered to be of minor importance, and hence time streams were developed for thinning without taking cooperation into account.

In the case of preventive spraying, lack of cooperation from owners of contigous lands was assumed to have no impact on the effectiveness of the treatment, which would still be 100% effective. However, the high cost would deter other owners, and hence there would still be beetles epidemic in the surrounding areas. This would mean that the wished-for effect of keeping the stand immune until the beetle was gone from the vicinity would probably be unsuccessful and therefore that the assumed two year delay until a new epidemic was probably reasonable.

4.0 IMPACTS OF BEETLE-KILLED TREES

Having developed the time-streams of trees killed under each option, we next needed to determine the effects of such beetle kills. After discussions with the PQ team, it was agreed that the major impacts would be related to four criteria, namely:

- timber value,
- recreation,
- scenic quality, and
- real estate value.

There is also an impact on fire hazard and in addition, the cost of each potential treatment was required in order to evaluate its desirability. As is described later in this section, timber value was decomposed into "capital" and "growth" sub-attributes and recreation was decomposed into "long-term" and "short-term" sub-attributes. This led to the complete breakdown for assessing effects being as shown in Exhibit 4-1. Note that fire is not included in this breakdown, for reasons soon to become clear.

For these criteria, both the number of trees killed and the timing of this kill were important to know, so the first stage of quantifying the impacts was to decide on a method for incorporating the time element. In this section we discuss first the method agreed upon, second the way that the fire hazard was treated and then, in turn, the way we quantified impacts on each criterion. Throughout the analysis, it was assumed that the needles on a tree would turn red the year the tree was killed, and would remain red for two years, after which time they would drop off. Further, the tree would remain standing for six years after it was killed, and would fall down in that sixth year.

4.1 The Time Element

As mentioned earlier, it was decided to use a twenty year time-horizon when evaluating treatment strategies for ponderosa pine. This was because of the

1.0 Timber

1.1 Capital

1.2 Growth

2.0 Real Estate Value

3.0 Recreation

3.1 Long-Term

3.2 Short-Term

4.0 Scenic Quality

5.0 Costs

EXHIBIT 4-1

Criteria for Assessing Effects of Mountain Pine Beetle

reasonableness of the assumption that no more than one epidemic would occur in a given stand during that time-period, and because no treatment has an effect lasting longer than about twenty years. Hence we can consider all occurrences further than 20 years into the future to be independent of our present action.

The reason that the time element is important is that effects, as well as costs, ten years in the future are of less concern than the same effects or costs incurred now. This problem is often dealt with by using a discount rate to weight the effects of future years. One method we could employ is to evaluate, on a year-by-year basis, the effect on each criterion of the beetle-kill, and then to use a discount factor to combine these numbers into a single measure of the effect on each criterion over the time horizon. (For a discussion of the assumptions that need to be satisfied to permit such a technique, see Keeney and Raiffa, 1976.) Such a procedure would be very complex and time consuming, and in view of the limited resources available for the analysis, an approximation to the more complex analysis was used.

The time stream of trees killed was parameterized with two values--the total number of trees killed, and the median year of the tree kill. By this second parameter we attempted to describe the "average" year in which the trees died; the year at which the epidemic was at its height. The values used are shown in Exhibit 4-2. The effects on each criterion were then calculated by assuming that all the beetle kill had occurred in that year, and then simply discounting the effect from that year. In this way we needed to discount only once for each time stream. So, for example in lands A, under no action with a mild epidemic, the median year was taken to be 3, and the total percentage of trees killed in the stand to be 25. Then the impact on each criterion of a 25% loss of trees was calculated, and this effect was discounted back to present-day values, under the assumption that it had all occurred three years in the future.

Discount rates of both 5% and 10% were used, in order to investigate the sensitivity of the results to the discount rate. The method used is of course only an approximation to complete discounting, but it gives very similar results with a great saving in time effort. We discuss further the impacts these assumptions have on the overall results in Section 7.0.

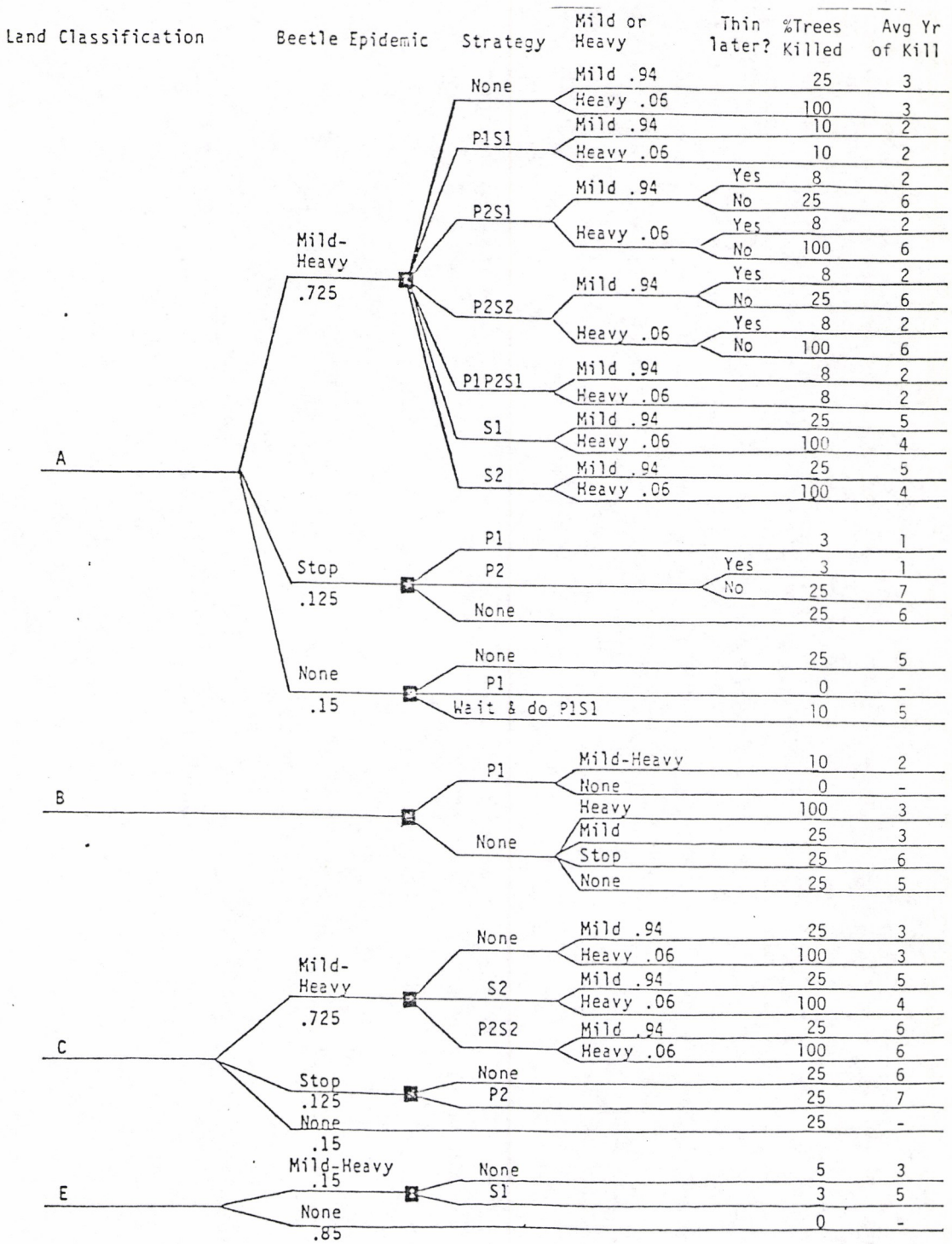


EXHIBIT 4-2

Percentage of Trees Killed Over Time Period and Average Year of Kill

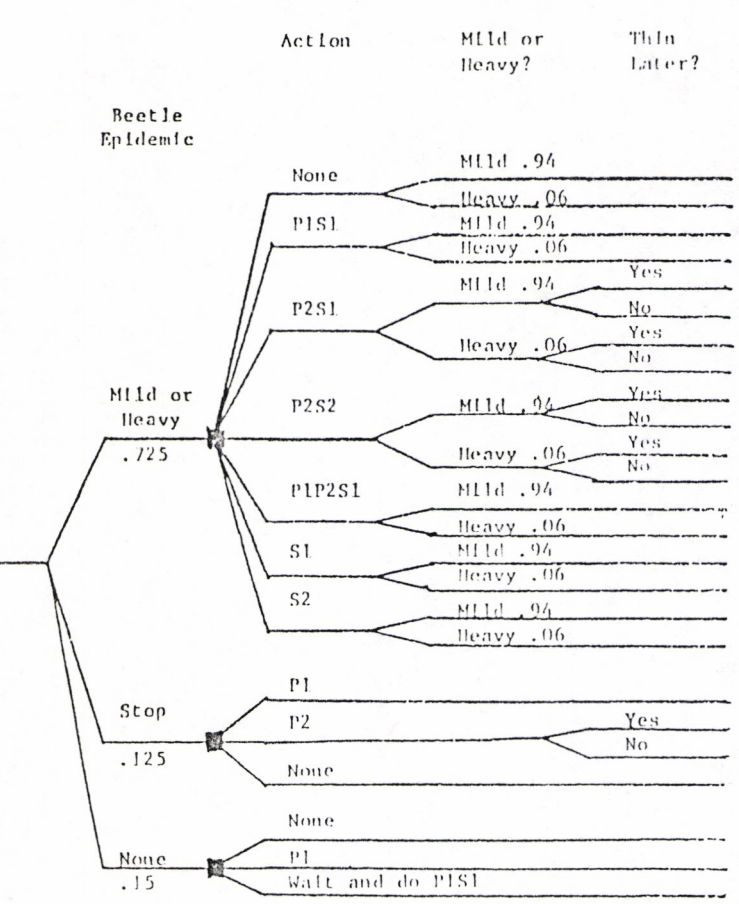
4.2 Fire Hazard

One of the effects both of trees being killed by the MPB, and of performing various treatments, is on the expected number of acres burned by wildfire, over the Region. The impact arises primarily from an alteration in the fuel bed. A computer model developed by the Forest Service was used to predict fire losses, under the various land types, treatments and outcomes. The primary outputs from the model are shown in Exhibits 4-3 and 4-4. For a fuller discussion of the modeling procedure used see the Planning Question 3 Final Report. The exhibits summarize the expected "acres burned per acre treated" over a 20-year period for each terminal node of the decision tree by three fire categories:

1. Crown fire
2. Fires in heavy blowdown fuels (over 50 downed trees per acre)
3. Fires in light surface fuels

In general, from 1/2 percent to 3 percent of the treated area can be expected to burn over the 20 years following treatment, depending on the treatment chosen. These results assume no fuel treatment of thinning slash. It was also assumed a) that beetle-killed trees are removed immediately for all prescriptions involving the S1 treatment, b) that beetle-killed trees are removed after three years in "accessible" areas where beetle activity is "heavy," and c) that beetled-killed trees are allowed to die, fall, and decompose without intervention where conditions described in (a) or (b) are not satisfied.

Differing amounts of beetle kill and different treatments would result in different proportions of the area expected to be burned over the twenty year time horizon. The program was run twice--once assuming total fuel treatment in thinned areas, and once assuming no fuel treatment. Since the differences between the effects were minimal (of the order of 0.1 percent of the acres) the rest of the analysis was conducted under the assumption of no fuel treatment, since such treatment appears not to be cost effective in this Region.



Expected Fraction of Area Burned Over 20 Years by Fire Type			
Crown	Heavy Surface	Light Surface	Total
.00965	0	.00400	.01365
.00416	0	.00417	.00833
.00109	0	.00427	.00536
.00109	0	.00427	.00536
.00109	0	.00427	.00536
0	0	.00430	.00430
.00109	0	.00427	.00536
0	0	.00430	.00430
.00406	0	.00418	.00824
.00912	0	.00402	.01314
.00149	0	.00426	.00575
.00505	0	.00415	.00920
.00109	0	.00427	.00536
.00109	0	.00427	.00536
0	0	.00430	.00430
0	0	.00430	.00430
.00805	0	.00405	.01210
.00575	0	.00412	.00987
.00344	0	.00420	.00764
.00296	0	.00421	.00717
.00774	0	.00406	.01180
.00882	0	.00403	.01285
.00862	0	.00403	.01265
.00109	0	.00427	.00536
.00109	0	.00427	.00536

EXHIBIT 4-3

Expected Area Burned Over 20 Years Assuming No Fuel Treatment - Lands A

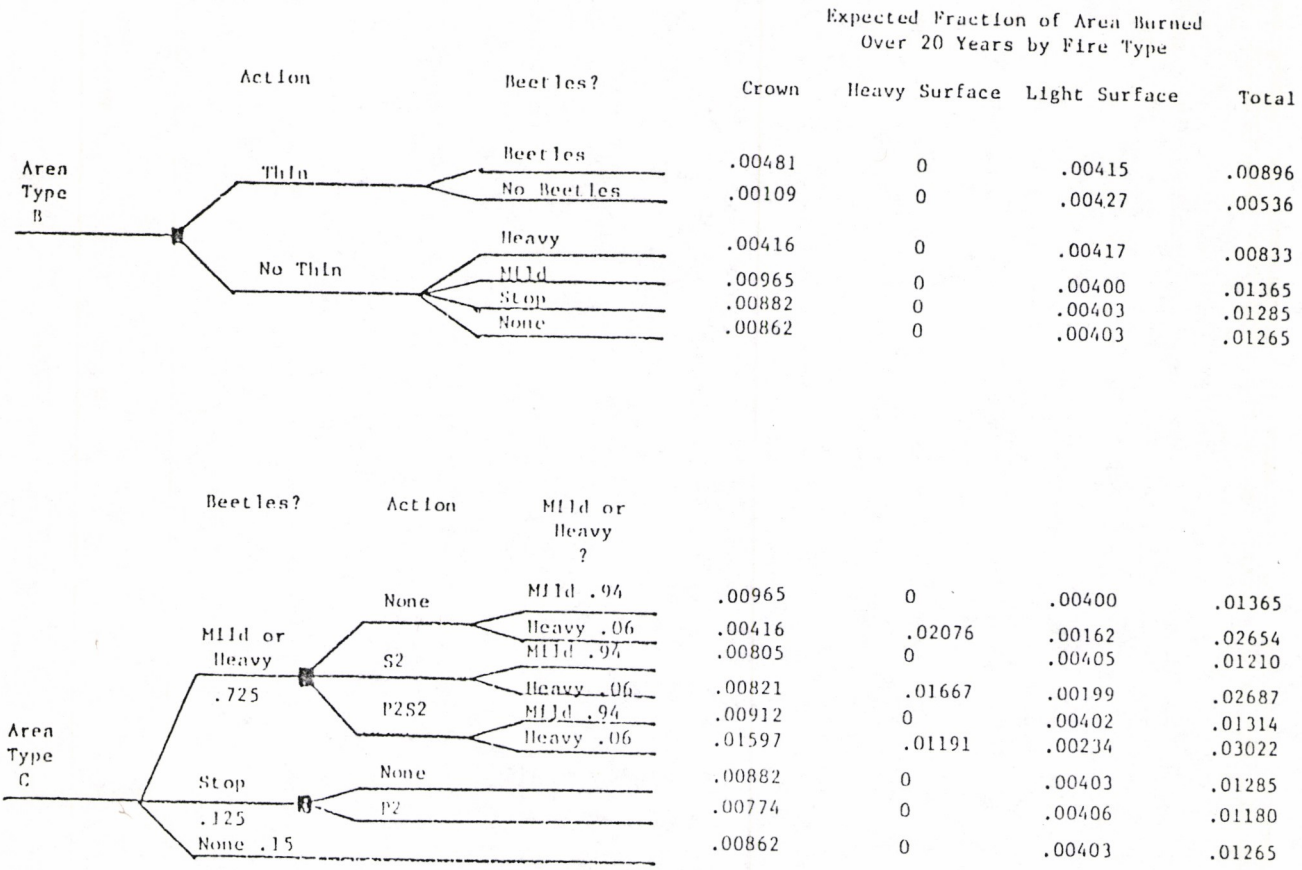


EXHIBIT 4-4

Expected Area Burned Over 20 Years Assuming No Fuel Treatment - Lands B and C

If, in fact, fuel treatment were to be carried out, the modified analysis would result in the same strategies being shown to be preferable, due to the small differences thus incurred.

The effects of fire were assumed to be incremental to the effects of the beetle, i.e., that the total fraction of area damaged was the sum of that damaged by pine beetles and that damaged by fire. Although this is a questionable assumption, the very small expected area burned means that, qualitatively, it is fairly accurate. In order to incorporate these figures into the analysis, we assumed that the impacts due to losing an acre from fire, on each criterion, would be approximately equal to those due to losing that acre from the MPB.

4.3 Costs

To calculate the costs per acre of the various treatments, information was elicited from the PQ team. They estimated that the value per stem of ponderosa pine was $3.20. They further stated that in areas where thinning was to be carried out it would be feasible to contract it out, in which case an immediate profit to the Forest Service would be realized, of about $2.20 per stem. Similarly, the PQ team stated that in areas of moderate-to-high susceptibility, harvesting of infested trees (S1) could also be contracted out as there would be enough such trees to make harvesting profitable. In such cases, there would be no net cost for the Forest Service. In those areas where harvesting was not profitable, a cost of $1.50/tree was used for S1. The Forest Service would always have to pay for chemical treatment and cost estimates for this analysis were $5/tree for preventive spraying, and $2/tree for chemical or other forms of direct suppression (S2). The PQ team also indicated that in those accessible areas obliterated by a heavy epidemic, the land manager would enter and reseed, at a total cost of about $475/acre.

From the above information, costs were derived for each branch of the decision tree, as shown in Exhibit 4-5. When the effects of timing of treatment were included, the cost in present-day dollars, at the 5% and 10% discount rates, was as shown in Exhibit 4-6.

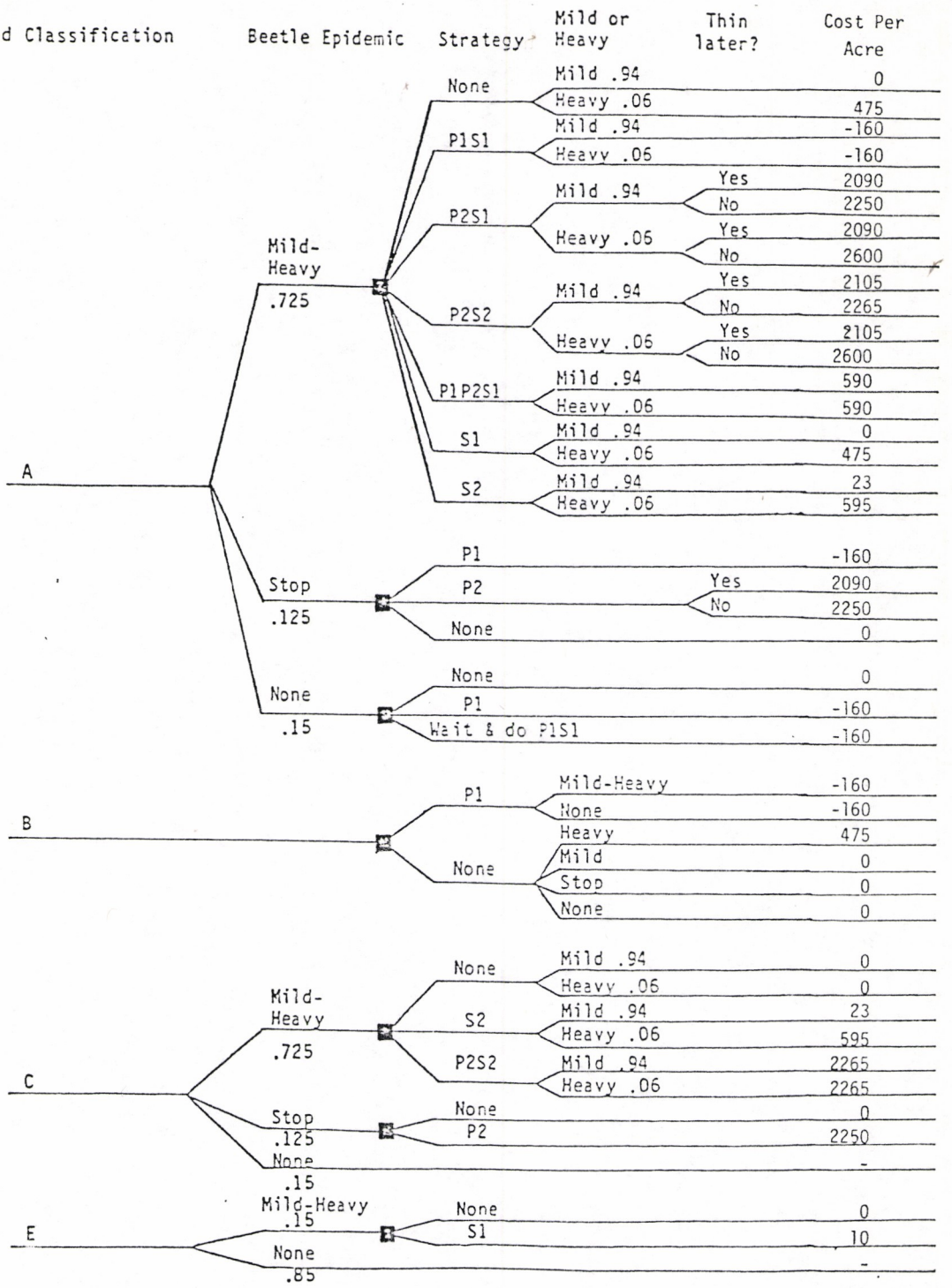


EXHIBIT 4-5

Costs of Treatment

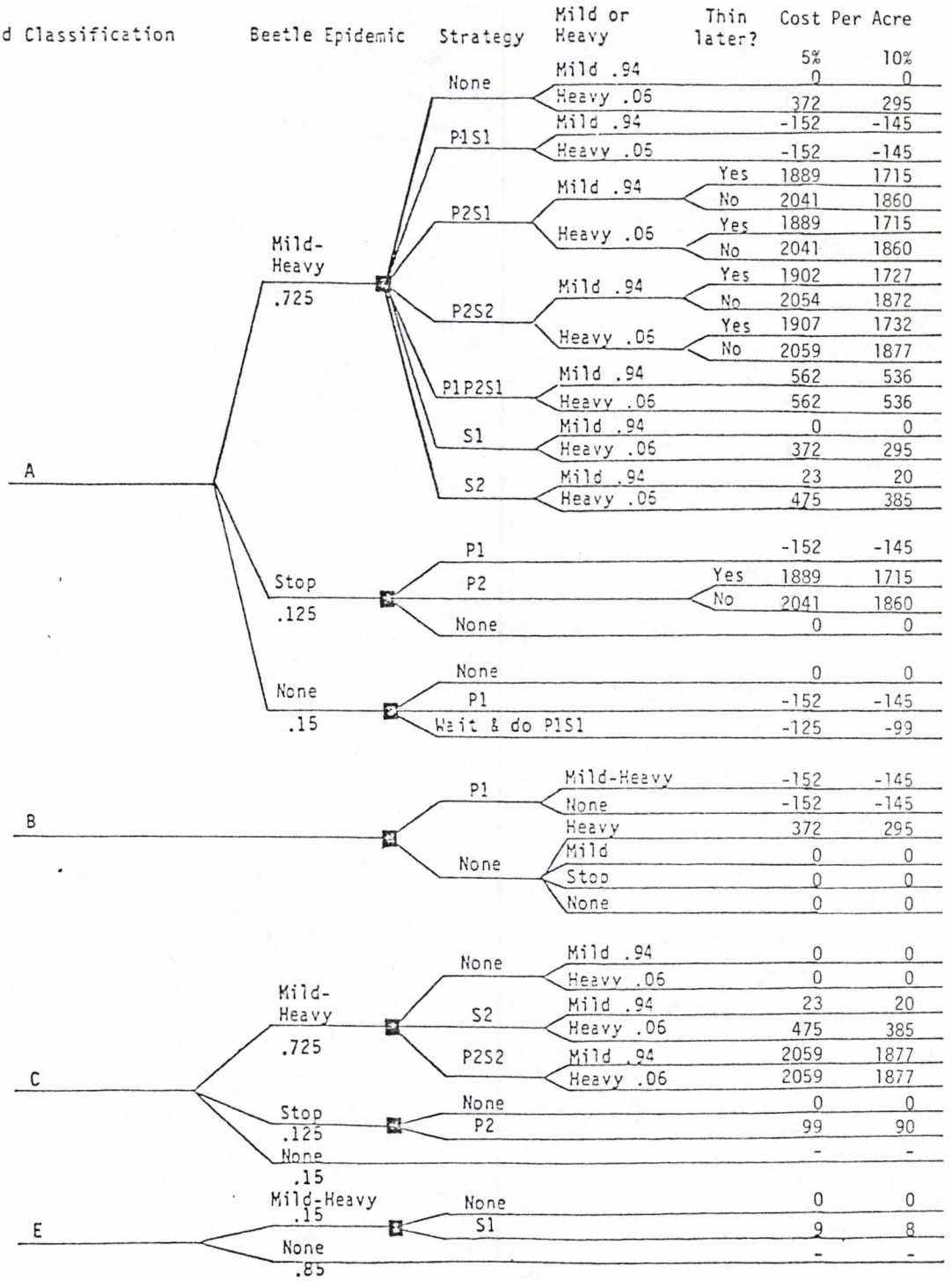


EXHIBIT 4-6

Discounted Costs of Treatment

4.4 Timber Values

The most obvious effect on the forests of having trees killed by the MPB is a reduction in timber value and in conjunction with the PQ team we evaluated these effects. It was agreed that there were two aspects of the timber value--the value of the stems standing in a stand, and the value of the new wood grown in the stand over the 20-year period. These we took as capital and growth, respectively.

To calculate the capital value of a stand, a value of $3.20/stem was used. The number of stems standing at the end of the 20-year period was calculated by using the figures for total number of trees killed by MPB, and the data on typical stands. In moderate-to-high susceptibility stands, after thinning, 75 stems would be left per acre; and without thinning, the beetle would kill 25 percent of the trees, except with a heavy epidemic, where no capital value would remain.

Thinning was assumed to have a beneficial effect on tree growth within a stand. Specifically, an unthinned stand would produce 250 board feet per acre per year (BF/Ac/yr); and a thinned one, 350 BF/Ac/yr. Using $3.20/100 BF as the value of this growth, the total dollar value of growth per acre under each of the different options was calculated. Areas which were wiped out by the epidemic were assumed to need more than twenty years to recover, and thus were valued at zero for timber.

The values calculated for each type of stand and treatment are shown in Exhibit 4-7. In the analysis these were assumed to be values realizable at the end of the 20-year time period, and were therefore discounted back to present-day dollars. It will be noted that, except in areas wiped out by the beetle, there was very little variation in total timber value between strategies. Thus, timber value was a relatively unimportant aspect for choosing among strategies. This lack of importance of timber values is born out by the analysis.

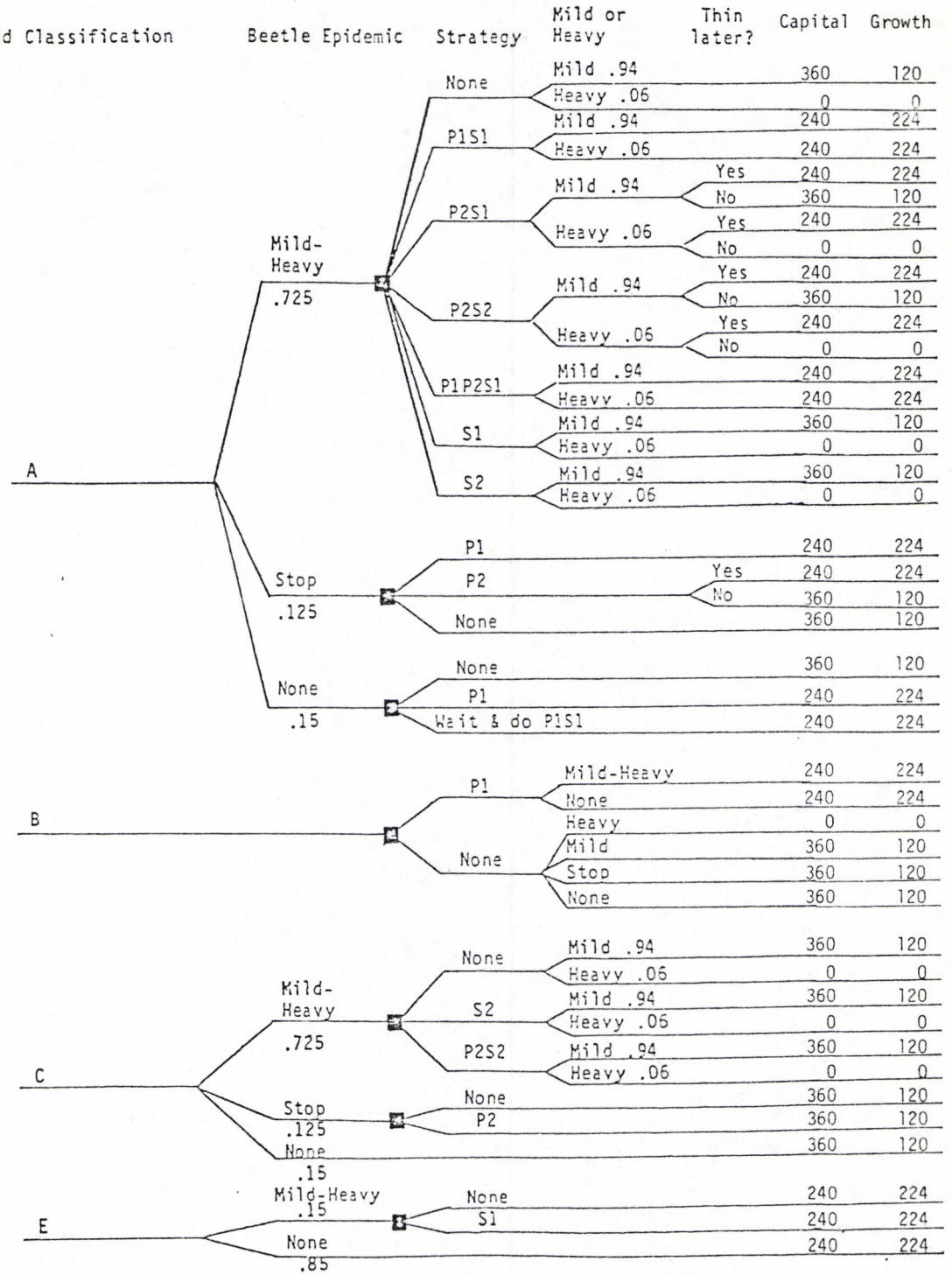


EXHIBIT 4-7

Timber Value

4.5 Subjective Attributes

The attributes which do differentiate greatly between alternatives are those describing reactions (to the MPB killed trees) of the public. The three facets of this that we decided to use related to recreation, visual quality, and real-estate value.

For each of these attributes we used a scale from 0 to 100 of subjective rating. Some research has been performed related to the perceived effects of MPB kills, but at present it is not very far advanced. Thus, we made some assumptions about these effects conforming to the preliminary results of the research, and to judgments from experts in the relevant fields.

The research shows that the major effects on these attributes is an adverse impact due to the needles turning red on recently killed trees. This impact is only a short-term one, lasting for two years after a tree is killed, after which time the needles fall off. It was judged that needle-less trees do not provide as much adverse effect, as they blend in well with other trees. There is also a major effect on recreation resulting from a large reduction in the total number of trees in a stand. The public appears to prefer well-stocked stands to thinned stands. This effect, which we considered to occur whenever a stand is thinned, is a longer term effect.

On the basis of preliminary results from research being performed by Dr. Richard Walsh of Colorado State University, together with prior research (Buhyoff and Leuschner, 1978), we decided to treat the short-term impacts on visual quality, real estate value, and recreation value as being proportional to the logarithm of the number of trees killed. Buhyoff and Leuschner have already shown such a model to give a good fit to data concerning visual quality; and Walsh's preliminary results indicate that the model is reasonable for the other two attributes.

Walsh's results also indicate that losing 15 percent of the trees loses 50 percent of the value, and with this data we were able to calculate scores for each

attribute on the 0 to 100 scale, where 100 represents negligible loss of trees; 50 represents loss of 15 percent of the trees immediately, and 0 represents loss of all trees immediately. The fact that the tree loss under different options occurred at different times (as shown in Exhibit 4-2) was taken into account by using the discounting ideas discussed in Section 4.1. To use the discounting factor, we assumed these effects, lasting as they do for two years after the tree is killed, had an average effect occurring one year after the average year of kill. The scores for those effects are shown in Exhibit 4-8.

The long-term impact due to thinning of stands was judged to last for five years, after which time the public would adjust its values and learn to appreciate the less densely stocked stands. The impact was once again scored on a subjective 0 to 100 scale, where 100 represents no thinning, and 0 represents the overall effects of immediate thinning, evaluated using a 5% discount rate. Since the effect would last for five years, the average year for the impact was taken to be three years after the thinning occurred. Hence the discount rate was important even for immediate thinning; since at a higher discount rate we are less concerned about effects in the future, thinning is less detrimental with the higher discount rate. These scores are shown in Exhibit 4-9 (note that the effect is not relevant on lands C and E, where thinning cannot occur).

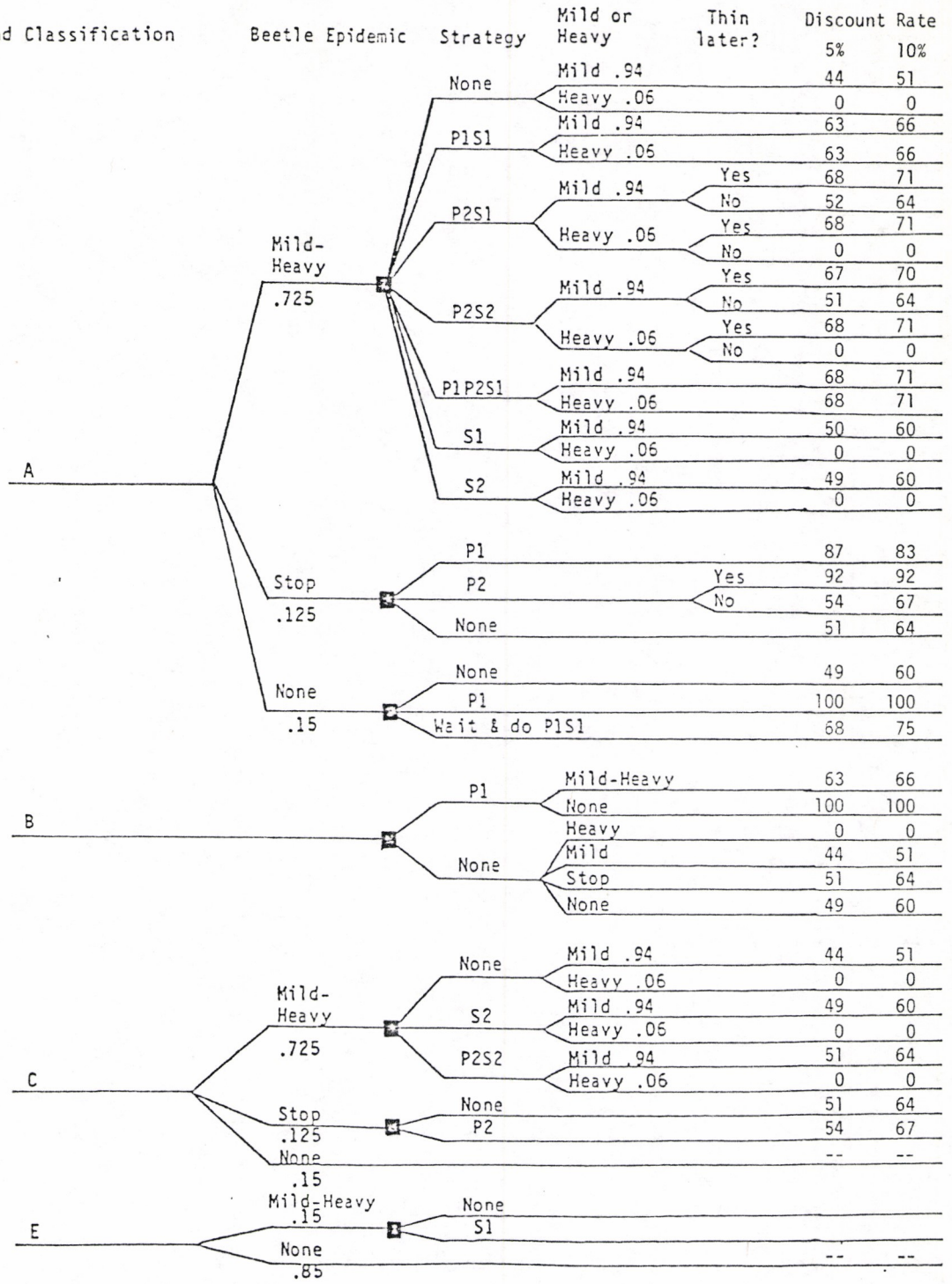


EXHIBIT 4-8

Impact on Real-Estate Value, Scenic Quality, and Short-Term Recreation

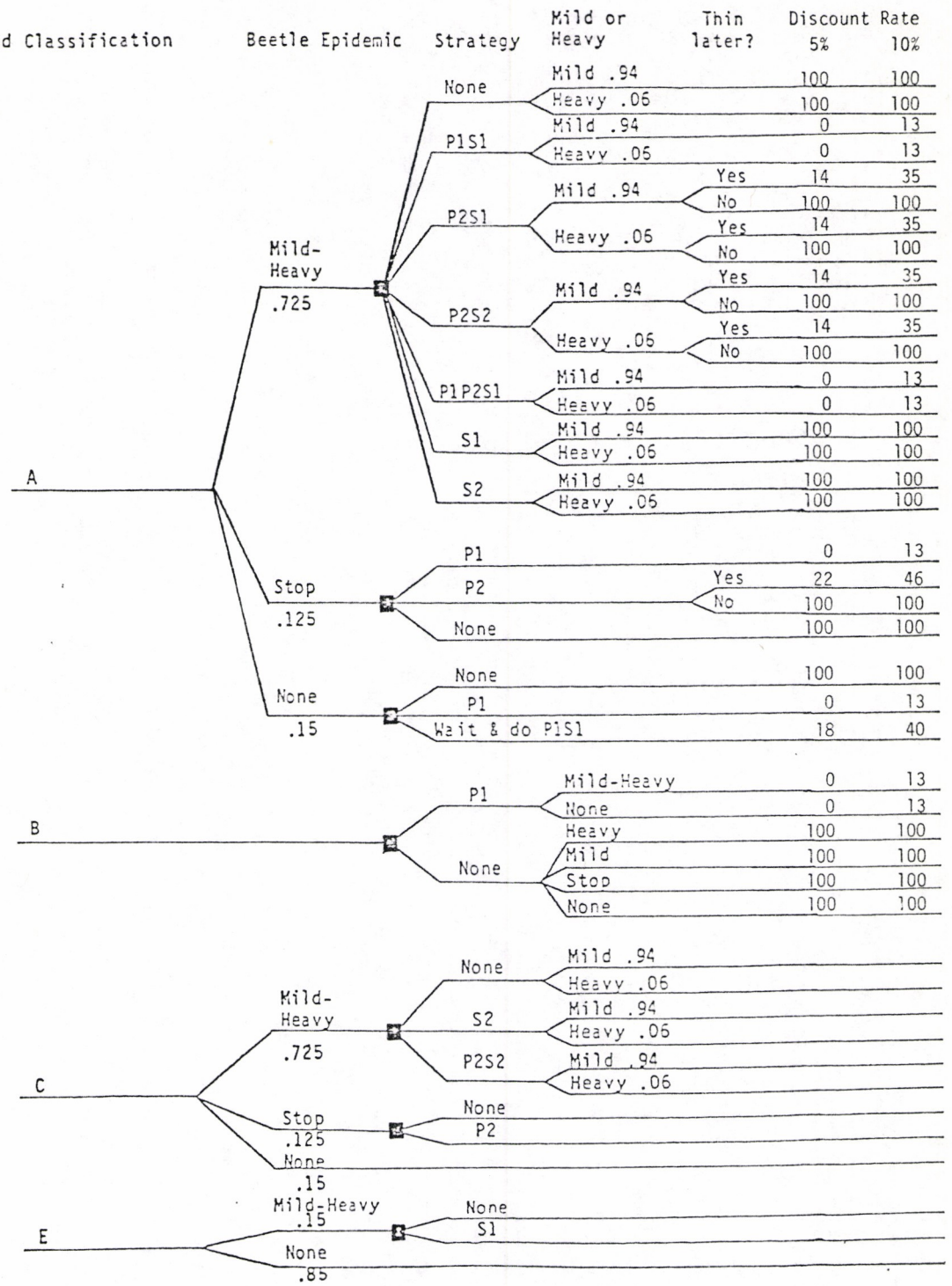


EXHIBIT 4-9

Long-Term Impact on Recreation from Thinning

5.0 TRADEOFFS AND RELATIVE VALUE

Having assessed the effect on each criterion resulting from each alternative, the next step in the analysis was to evaluate the tradeoffs among the effects on the different criteria. The procedure we used to combine these effects into a single measure of the value of each alternative involved the use of an additive multiattribute utility (MAU) model (see Appendix A).

5.1 Single-attribute Utilities

The first step in the procedure was to transform all the effects discussed in 4.0 into easily commensurable scales. It was decided to keep all non-monetary impacts on a 0 to 100 scale, but monetary aspects were transformed into a -100 to 100 scale. Here negative numbers denote costs incurred and positive numbers denote profits gained. For each monetary criterion, the value was assumed to be proportional to the number of dollars. Specifically, for costs incurred, the worst case (see Exhibit 4-6) was 2059 present-day dollars (for P2S2, no thin, 5% discount rate) and this defined the -100 point on the cost scale. Then a cost of exactly half this (1029.5 present day dollars) would score -50; no cost would score zero; a profit of $100 would score +7, etc. Timber value was scored similarly on two 0 to 100 scales, one each for capital and growth. For capital, 100 represented $360 value in 20 years time, discounted at 5% interest. In each case, zero represented no value.

We had thus transformed all the effects on each criterion into values between -100 and +100. These values are termed the "single-attribute utilities." The next stage in the analysis was to combine the single-attribute utilities of the different criteria in each year for each alternative, into a single value (the multiattribute utility) for each of the alternatives in each year. This multiattribute utility is a weighted average of the single-attribute utilities. The weights are subjective values, representing the tradeoffs among the different criteria. The method of assessment was that of "ratio weights." This technique requires the assessor to decide upon the value of moving from 0 to 100 on one attribute, relative to moving from 0 to 100 along a second attribute (while keeping all other attributes at the same level). If the second change

were considered to be twice as good as the first, then the weight on the second attribute would be twice that on the first. By comparing different pairs of attributes in a similar manner, the relative weights for each of the attributes can be determined. The weights to be used in the weighted average are then normalized to sum to one. (This keeps the relative weights the same.)

Weights were assessed by the PQ3 team, representing the Forest Service; and in addition we interviewed representatives of various interest groups to obtain weights representing their values (which were expected to vary from each other, and from those of the PQ3 Team). These interviews were conducted, and weights were obtained, to assist the Forest Service in incorporating public issues and values into its planning process. These groups were the Colorado Division of Wildlife, an advisory council on off-road vehicle recreation, and the Sierra Club.

5.2 Assessed Weights

When interviewing the PQ3 Team, it became clear that there were two different conceptions of "high-value areas." Those classified in Exhibit 2-1 as high-value are lands in or around developed recreation sites. These are, however, areas of exceptional scenic quality, or offering good recreational experiences, classified in Exhibit 2-1 as low-value lands. In such areas, all strategies may be worth considering. We therefore looked at them under lands A, C, and E, and termed them "medium-value" lands, as their perceived value/acre will typically be less than developed recreation sites. Weights were then assessed by PQ3 Team members for each of these types of land under the names of FS High and FS Medium, for lands A, C, and E.

When computing these weights, we assumed that the ratios between cost and timber value weights were the same as the ratio between the number of dollars represented by the range between zero and 100, i.e., a difference of 100 on the cost scale represented 2059 present day dollars and a similar difference on the timber scale represented about 220 present day dollars, so a change of 100 on the cost scale is nine times as important as a 100-point change on the timber scale. This is reflected in the relative weights; that for cost is nine times that for timber.

Weights for low-value lands were derived from those of FS medium by assuming the total non-monetary value of the land to be equal to the timber value (reflecting the lower overall value of the land) and the ratios between the weights on the non-monetary criteria to be the same as with FS Medium.

The weights assessed from the other constituencies for lands A, C, and E were for "medium-value" lands. We found that it was generally agreed that on developed recreation sites recreation was the most important aspect, and the analysis for such lands could best be performed using sensitivity analysis, as described in Section 6.0. The full set of weights for the different land types is shown in Exhibit 5-1.

A few comments are necessary to explain this exhibit. Only one set of values was obtained by interview--those for lands A with beetles. We now discuss the assumptions underlying the differing weights for other lands. First, the figures for land A (No Beetles), and lands B have equal weights for timber value and cost because here none of the very expensive P2 options were viable, and so the maximum potential cost was far less. Therefore the cost scale was altered to have the same range as the timber value scale, and hence the same weight. There is no weight on real-estate value for lands B and C because as described above, they were assumed to have no real-estate value. The two options of doing nothing or S1 resulted in the same timber value. This criterion would not distinguish between the alternatives, and so was not used for those lands.

A look at these weights reveals some very great differences among the interest groups. As expected, FS High had very high weight on recreation, but also a high weight on costs--we are, after all, talking of areas where the Forest Service will largely bare that cost. This is even more apparent with FS Medium. The other groups put much less weight on cost, with the notable exception of the Sierra Club. Their very high weight on cost and zero weights on recreation and scenic quality may appear very strange initially, and possibly at variance with their usually expressed opinions. Such an inconsistency disappears when one looks again at the meaning of these weights. We were asking about the relative importance of certain impacts on recreation or scenic

	Timber	Real Estate	Recre-ation	Scenic	Cost
A					
FS High	.04	.02	.53	.07	.34
FS Medium	.08	.04	.12	.04	.72
Wildlife	.02	0	.45	.36	.18
OHV User	.02	.04	.42	.31	.21
Sierra	.08	.23	0	0	.69
A--No Beetles					
FS High	.05	.03	.77	.1	.05
FS Medium	.22	.11	.33	.11	.22
Wildlife	.02	0	.53	.42	.02
OHV User	.03	.04	.52	.33	.03
Sierra	.2	.6	0	0	.2
B					
FS	.33	.07	.2	.07	.33
Wildlife	.33	0	.19	.15	.33
OHV	.33	.02	.18	.13	.33
Sierra	.5				.5
C					
FS High	.05	0	.49	.02	.44
FS Medium	.09	0	.09	.04	.78
Wildlife	.02	0	.35	.41	.22
OHV	.03	0	.34	.37	.26
Sierra	.1	0	0	0	.9
E					
FS High		.04	.74	.15	.07
FS Medium		.17	.33	.17	.33
Wildlife			.44	.53	.03
OHV		.05	.43	.48	.04
Sierra		.5			.5

EXHIBIT 5-1

Weights Assigned to MPB Effects

quality arising from MPB kills. This is the key point so far as the Sierra Club is concerned. They view the MPB as a natural phenomenon, and therefore as much a part of our environment as trees and mountains. Activities of the MPB thus do not worry the Sierra Club (or at least the representative to whom we talked) except with regard to the economic effects. It is for this reason that they gave a relatively high weight to real-estate value, which was unimportant to all other constituencies. Another way of understanding these differences is offered by the figures in Exhibits 5-2 and 5-3. These show the total equivalent value of an acre of each type of land implied by the weights of the different constituencies, and the approximate equivalent dollar value per tree on each type of land (the timber value per tree was taken as being about 1-1/3 present day dollars). It will be seen from figures that the Sierra Club values these lands at little above their timber value, which again may appear strange until we remember that these values are in fact measures of the maximum number of Forest Service dollars that each constituency feels it would be worth to change from total annihilation due to MPB, to no MPB damage at all. The Sierra Club does not feel that many dollars should be spent to offset this natural phenomenon.

Values for lands C are slightly less than for lands A, because there is no real estate value, and lower on lands E because of the preference of people for more densely stocked stands. The individual tree value is higher on lands E as there are less trees per acre. In the two instances where major criteria were subdivided; timber and recreation; weights were also needed for the subcriteria. In the case of timber these weights were simply determined by using the ratio of the ranges for capital and growth, since these were both dollar values. Since the range for capital was $360 and for growth $226, the ratio was 1.6:1, providing normalized weights of 0.62 and 0.38. For recreation the judgmental data showed that thinning would result in a 20% reduction in the quality of experience for 5 years, and this was assumed to be of equal importance to a reduction of 50% for two years. The first results in a change from 100 to zero on the long-term recreation scale, and the second results in a change from 100 to 50 on the short-term recreation scale. Hence the ratio of weight was taken to be 2:1 with the normalized weights being 0.33 for long-term recreation and 0.67 for short-term recreation.

Land Type	FS High	FS Medium	Wildlife	OHV	Sierra
A	3960	784	9184	7505	900
B	400	400	400	400	200
C	3680	680	8700	7000	200
E	2800	600	7000	5200	200

EXHIBIT 5-2

Equivalent Dollar Values of One Acre of Land,
by Constituency and Land Type

Land Type	FS High	FS Medium	Wildlife	OHV	Sierra
A	26	5	60	50	6
B	2.5	2.5	2.5	2.5	1.3
C	25	4.5	58	47	1.3
E	38	8	94	70	2.7

EXHIBIT 5-3

Equivalent Dollar Value per Tree,
by Constituency and Land Type

At this stage we had obtained all the judgmental data required for the additive multiattribute utility model, and were able to compute the results of our analysis. This forms the subject of the next section.

6.0 RESULTS OF ANALYSIS

6.1 Overall Results

The data discussed in the previous sections were analyzed using computer software developed by DSC. The results for each type of land are shown in Exhibit 6-1. The numbers in each column are the expected utilities by alternative, for each type of land, for a particular interest group, at a particular discount rate. It should be noted that the numbers are not to be compared across interest groups, or for different types of land, as there are different units in such cases. Comparisons should be made for each interest group at each discount rate within each type of land. This has been done as is shown by the asterisks which are beside the highest number--indicating the preferred alternative. The results are summarized in Exhibit 6-2, which show the preferred alternatives.

Two facts become quickly apparent on studying these results. First, the discount rate does not have much impact on preferred alternatives. Second, in spite of the very different weights of the various constituencies, there is substantial agreement among them concerning the best alternative. It is also apparent that the P2 options are universally considered poor.

The major disagreements arise between FS Medium and the Sierra Club on the one hand, and FS High, Wildlife interest, and OHV (off-highway vehicle) users on the other hand. The former prefer thinning on high-value accessible and susceptible lands with an epidemic in progress, and no action on inaccessible such lands; whereas the latter prefer harvesting of infected trees on the accessible lands and chemical suppression on the inaccessible ones. This difference arises directly from the fact that FS Medium and the Sierra Club have lower values in general for these lands and the potential impacts of MPB on non-market outputs, and specifically, lower values for the recreational aspects. Since thinning has an adverse impact on recreation, those interest groups with high recreation weights like thinning less on Lands A. For Lands C, the cost of suppression is viewed as too great for its benefits by FS Medium and the Sierra Club, whereas the other interest groups value the benefits more highly relative to cost and thus consider it worthwhile.

Constituency	FS High		FS Medium		Wildlife		OHV Use		Sierra Club	
Discount Rate	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%
Lands A -Medium or Heavy Action:										
Nothing	39	40	16	13	43	46	42	45	15	13
P1S1	33	35	*21	*19	44	47	43	45	*26	*22
P2S1	6	13	-52	-47	30	37	26	33	-47	-43
P2S2	6	12	-52	-48	30	37	26	32	-48	-44
P1P2S1	24	26	-2	-4	41	44	57	59	3	1
S1	*41	*44	17	15	*47	*52	*58	*63	16	15
S2	40	43	16	14	46	52	57	63	15	14
Lands A -Stopped										
Nothing	*44	*47	19	17	49	57	48	55	18	17
P2	14	20	-48	-44	41	47	36	43	-43	-39
P1	*44	44	*25	*21	*59	*60	*58	*57	*31	*27
Lands A -No Beetles										
Nothing	61	66	51	45	58	65	57	64	46	42
P1	*72	*72	*77	*67	*81	*82	*81	*82	*90	*79
Wait	55	62	63	55	59	67	59	67	68	60
Lands B	1/									
Thin	--	--	*63	*47	*68	*52	*67	*51	*74	*48
Dont Thin	--	--	39	25	42	29	41	28	36	13
Lands C -Medium or Heavy										
Nothing	25	26	*12	*9	33	37	32	35	*8	*3
S2	*26	*29	11	8	*36	*43	*34	*40	6	1
P2S2	-16	-8	-65	-61	17	27	10	20	-82	-79
Lands C -Stopped										
Nothing	*27	*34	*40	*50	*7	*9	*38	*47	*0	*0
P2	-17	-5	21	33	-77	-68	14	26	-99	-90
Lands E -Beetles										
Nothing	72	74	52	53	76	78	75	77	39	40
S1	*91	*91	*61	*61	97	97	*96	*96	*42	*42

1/ Since Lands B are of low value, they could not be developed recreation sites, and hence did not have any FSHIGH assessments or results.

EXHIBIT 6-1
Overall Results

Constituency	FS High		FS Medium		Wildlife		OHV Use		Sierra Club	
Discount Rate	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%
Lands A -Medium or Heavy	S1	S1	P1S1	P1S1	S1	S1	S1	S1	P1S1	P1S1
Lands A -Stopped	None/ P1	None	P1	P1	P1	P1	P1	P1	P1	P1
Lands A -No Beetles	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Lands B	--	--	Thin	Thin	Thin	Thin	Thin	Thin	Thin	Thin
Lands C -Medium or Heavy	S2	S2	None	None	S2	S2	S2	S2	None	None
Lands C -Stopped	None	None	None	None	None	None	None	None	None	None
Lands E -Beetles	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1

EXHIBIT 6-2
Preferred Action by Land Type, Constituency and Discount Rate

6.2 Sensitivity Analyses

In order to gain a better understanding of the overall results, extensive sensitivity analyses were performed. An initial examination of the results of the basic analysis shows that the two crucial factors affecting preferences are the overall value placed on an acre, and the amount of importance placed on possible adverse impacts on recreation. We therefore concentrated our sensitivity analyses on these two aspects of the problem.

The sensitivity to overall value of the land was investigated by varying the weight on the cost attribute. This works because the lower the weight placed on cost, the higher we must be valuing the trees on that acre. For example, for FS High, Lands A with bettles, the weight on Cost was 0.34, and the weight on the other criteria, was 0.66. Thus a change from 0 to 100 on the cost scale (representing about $2,000) was worth 0.34/0.66 = 51% of a change from 0 to 100 on the other attributes. These other attributes represent the total value the constituency places on the trees in an acre, consisting of the timber, visual, recreational and real-estate values. Thus a change from 0 to 100 on all of these criteria represents the change in value from having no trees to all trees. Since the $2,000 cost is valued by FS High at 51% of this change, we may deduce that the total value arising from the trees is about $3,900/acre, for FS High. Were the weight on cost changed to 0.2, then the $2,000 would be worth 0.2/0.8 = 25% of the perceived tree value of the land, which would thus be approximately $8,000.

Sensitivity analyses were performed on the cost weight for all constituencies and land types. The results are presented only for the 10% discount rate, as there was no fundamental difference between the results for the two discount rates. As might have been anticipated from the overall results, the preferred alternative did not shift at all except for Lands A and Lands C--Medium or Heavy, so we may be very confident in the recommendations for Lands B, Lands C--stopped, and Lands E.

Exhibit 6-3 shows the sensitivity on Lands A mild or heavy, for the FS Medium constituency, to the weight on cost. We only show the values for S1 and P1S1 and no action, as these options dominated the others over all possible values of cost. The exhibit shows that for weights below 0.47 suppression (S1) is preferred, while for weights above 0.47 P1S1 is preferred. The implied value of the land at this weight is just over $2,300 per acre. Exhibits 6-4 and 6-5 shows the same sensitivity analysis for the Wildlife and OHV user constituencies, and here again a crossover point appears at 0.47. The disagreement as to action shown in Exhibit 6-2 is thus explained. All constituencies (except the Sierra Club) agree that for lands valued at more than about $2,300/acre suppression is the best option, whereas for lands valued at less, P1S1 is preferred. However the Forest Service values areas which are not developed recreation sites, lower than other constituencies (about $800/acre) and thus prefers P1S1. A more detailed explanation of the recommendations arising from these results is deferred to Section 6.3.

Exhibits 6-6 and 6-7 show the sensitivity of FS High and FS Medium to the weight on cost for Lands A-stopped. The other constituencies showed insensitivity to these weights. As can be seen there is no real sensitivity for FS Medium--the preferred alternative shifts only for weights lower than 0.2, and this is far below the assessed value. For FS High, there is a shift to preferring P1 if cost has weight above 0.6, but this is unreasonable in the developed recreation sites under consideration since this would imply a very low value. There is also a shift to preferring P2 if the weight is below 0.04, i.e. if we value the land at more than about $50,000/acre; or $333/tree. This may be feasible in some sites.

In Lands C, no sensitivity was shown to value except for the FS Medium constituency in the "mild or heavy" category. The results for this constituency are shown in Exhibit 6-8. There is a shift in preference at a weight of 0.72, very close to the assessed weight of 0.78. This means that if the lands were valued slightly higher by the Forest Service, the preferred alternative would become suppression, in agreement with the Wildlife and OHV constituencies.

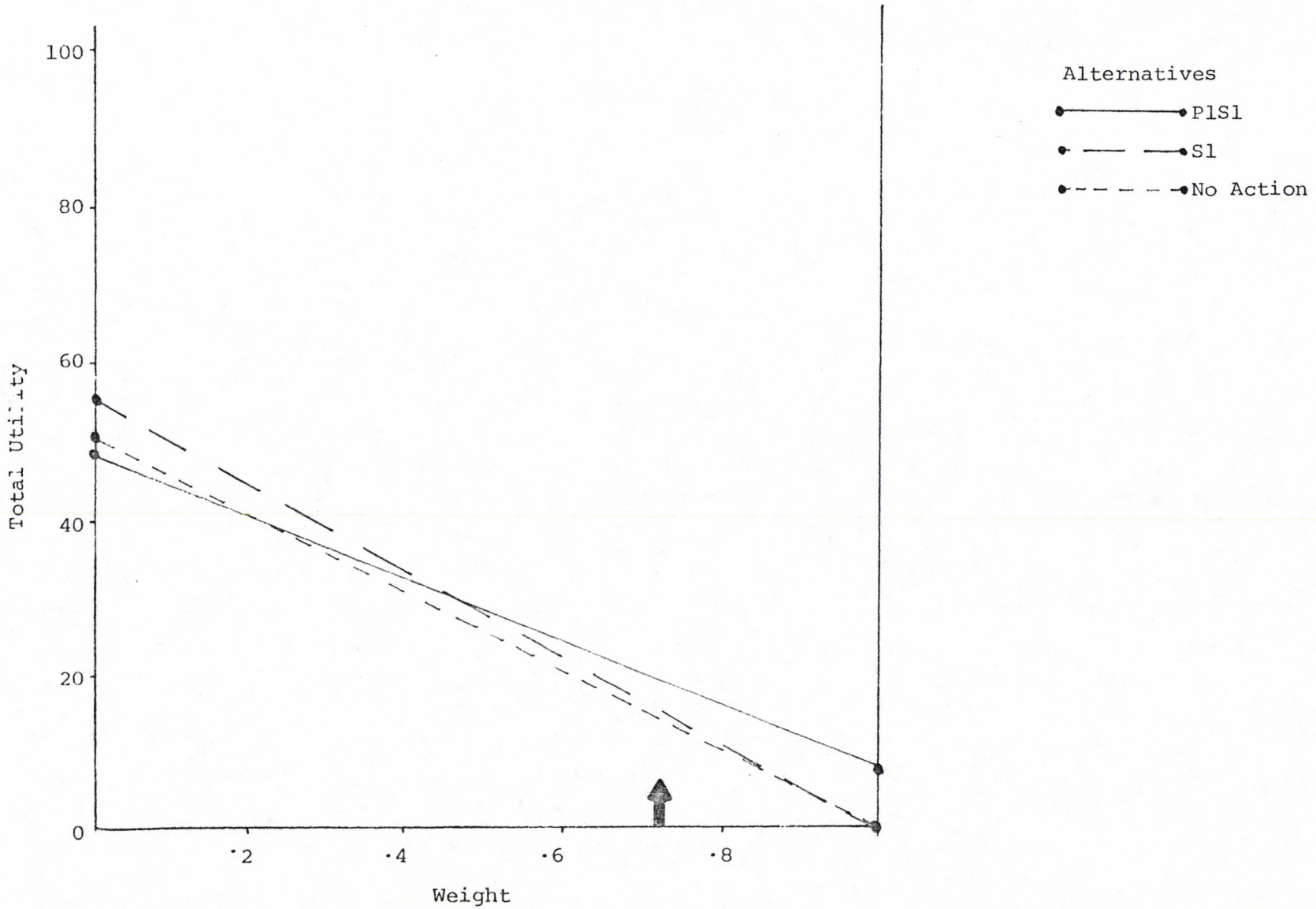


EXHIBIT 6-3

Sensitivity of FS Medium Evaluation to Weight Assigned to Costs
Lands A - Mild or Heavy

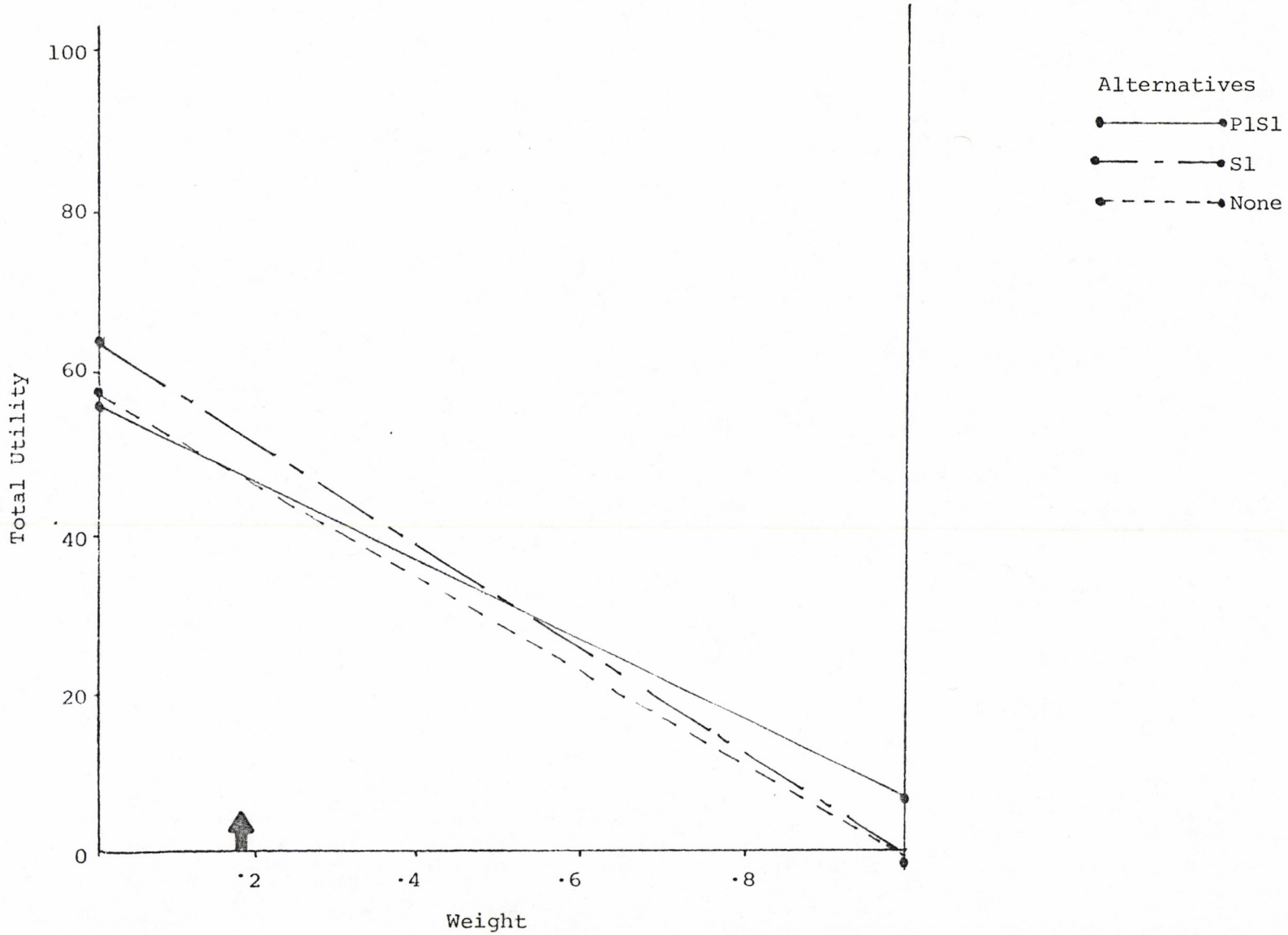


EXHIBIT 6-4

Sensitivity of Wildlife Constituency Evaluation to Weight Assigned to Costs
Lands A - Mild or Heavy

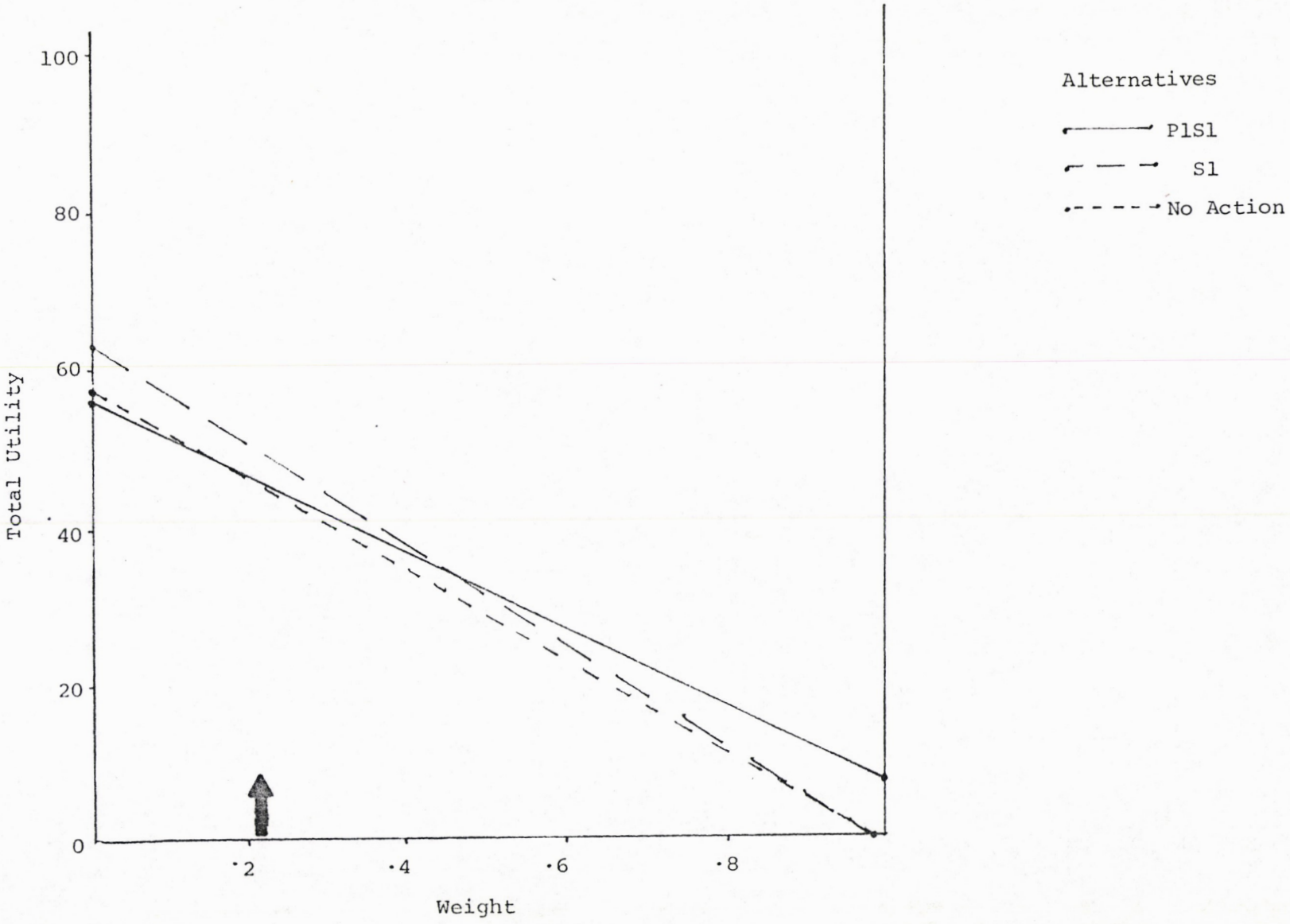


EXHIBIT 6-5

Sensitivity of OHV User Evaluation to Weight Assigned to Costs
Lands A - Mild or Heavy

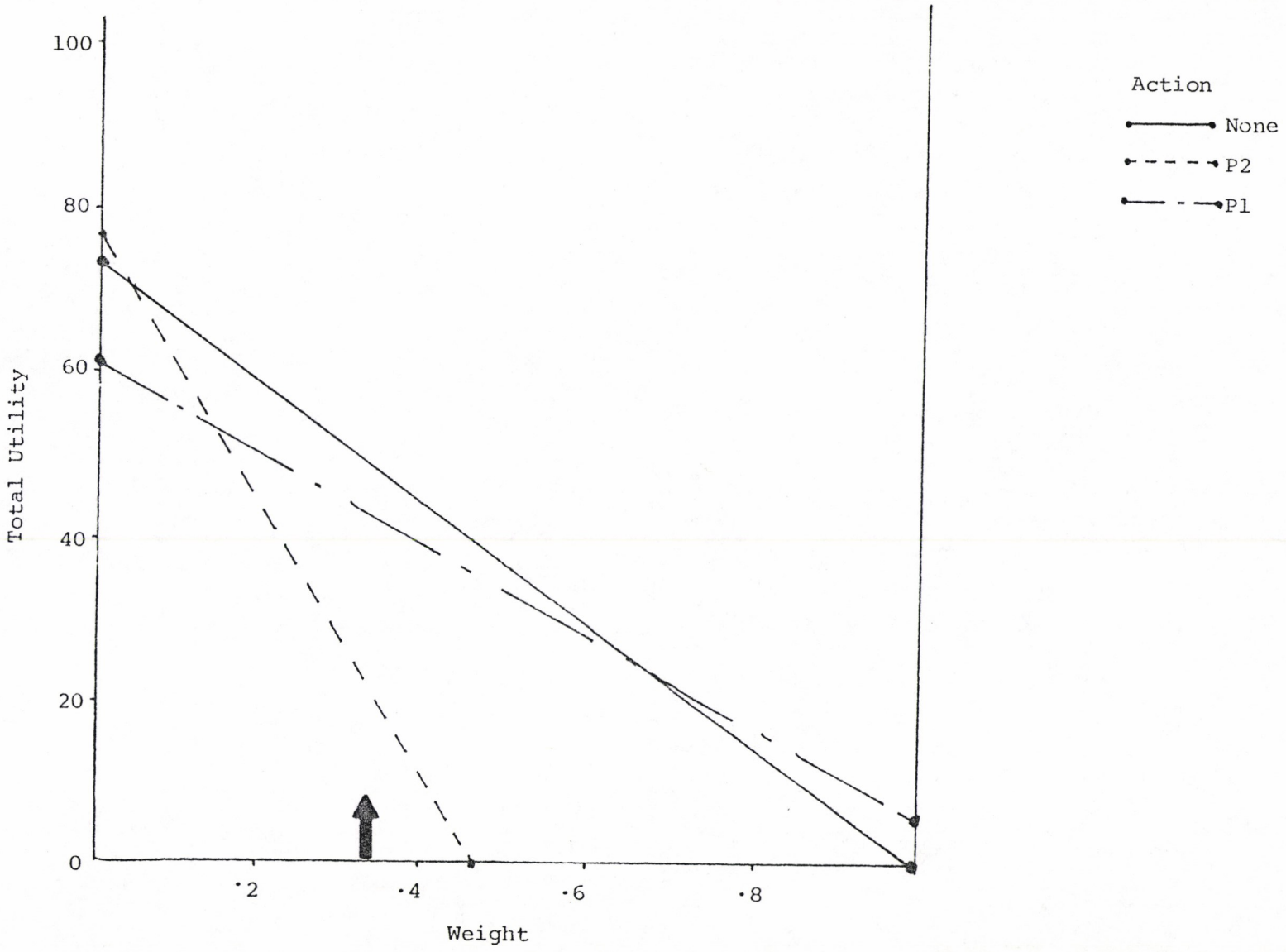


EXHIBIT 6-6

Sensitivity of FS High Evaluation to Weight Assigned to Costs
Lands A - Stopped

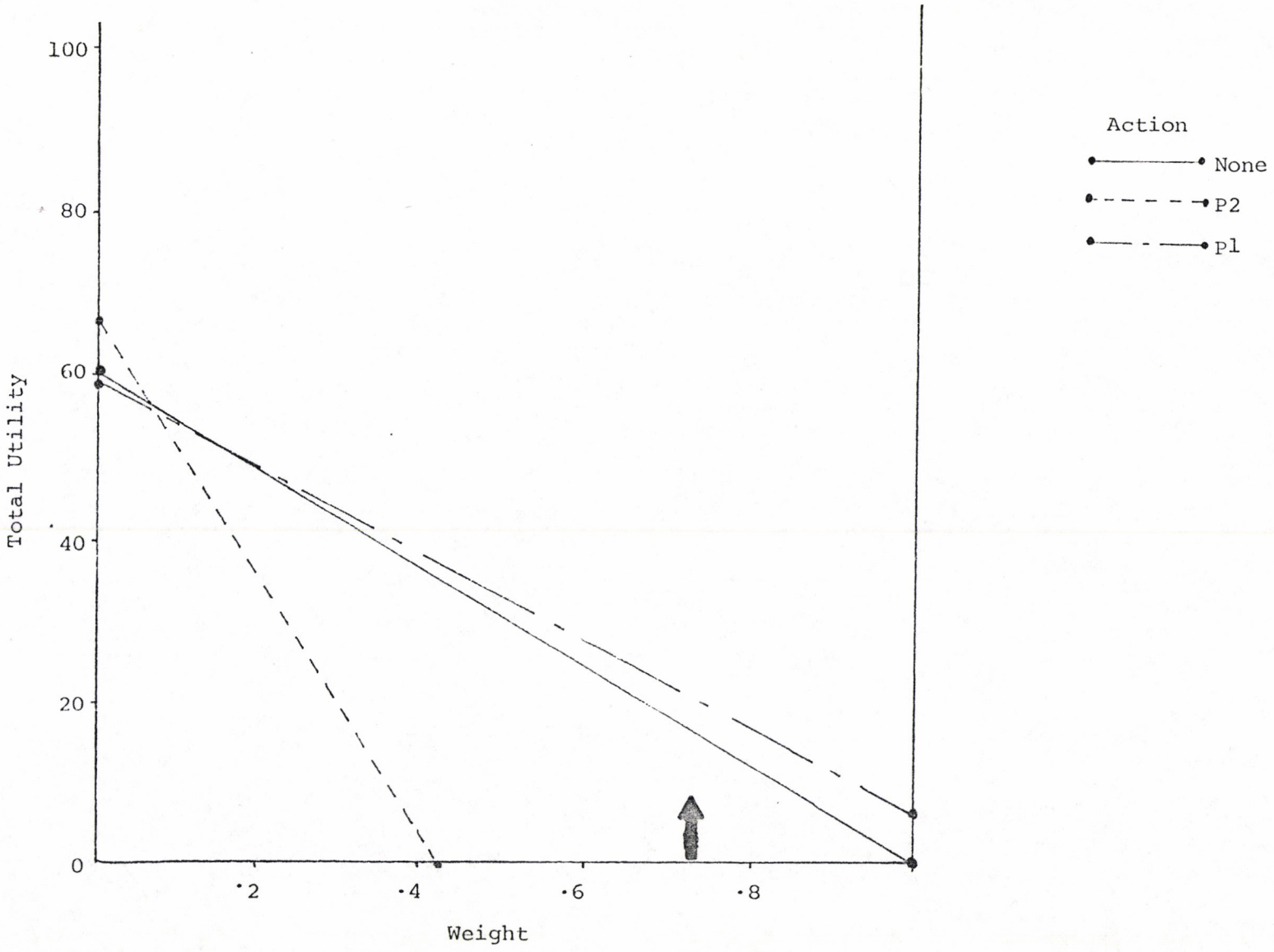


EXHIBIT 6-7

Sensitivity of FS Medium Evaluation to Weight Assigned to Cost
Lands A - Stopped

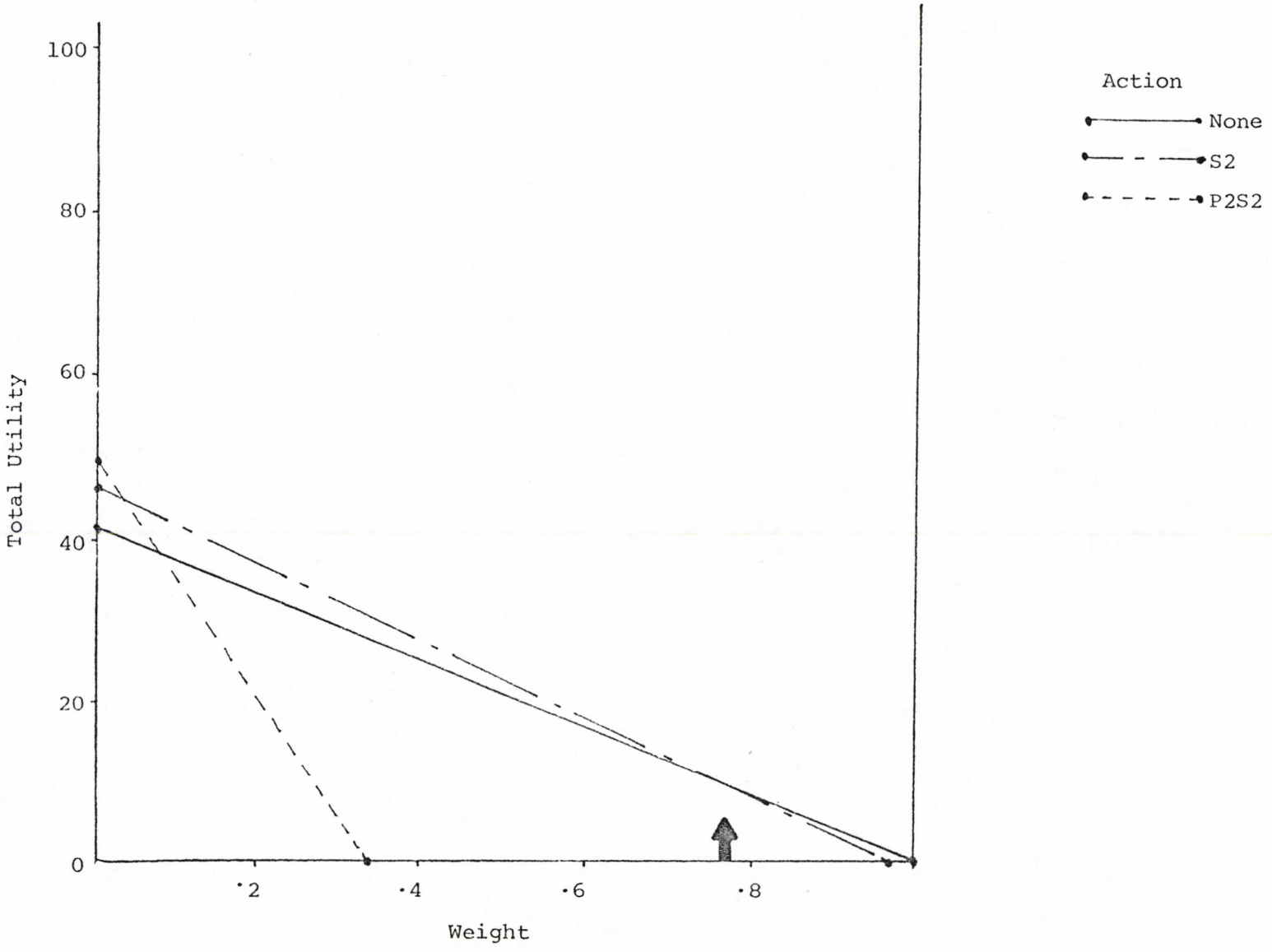


EXHIBIT 6-8

Sensitivity of FS Medium Evaluation to Weight Assigned to Costs
Lands C - Mild or Heavy

The other weight to which the evaluations showed any sensitivity was that on recreation. This arises because thinning produces an initially adverse impact on recreation. The only sensitivity was for Lands A.

Exhibit 6-9 shows the sensitivity of the FS Medium evaluation to this weight with beetles present. As with the weight on costs, the sensitivity graphs for Wildlife and OHV Users were very similar to that for FS Medium. P1S1 becomes the preferred option when the weight is below 0.26. As can be seen from Exhibit 6-9, the Forest Service weight lies below this value; the other constituencies above. The Forest Service would need to nearly double its weight before preferring suppression. (Note that we are talking here about the high value lands which are not developed recreation sites. On the recreation sites, evaluated by FS High, suppression was unequivocally preferred.)

Exhibits 6-10 to 6-12 show the sensitivity of FS Medium, Wildlife, and OHV Users constituencies, respectively, to the recreation weight in Lands A-stopped. In each case the weight on recreation needs to be raised, before doing nothing becomes a preferred option; for the Forest Service from 0.12 to 0.32; for Wildlife interests from 0.45 to 0.56, for OHV Uses from 0.42 to 0.48. Thus, on those high value lands with slightly more recreational value than the average, P1S1 becomes a far less attractive option.

The final evaluation showing a sensitivity to an assigned weight was that for FS High in Lands A without beetles. In this case, the major weight is on recreation and an increase in this weight is equivalent to saying the developed recreation site is of greater value. Exhibit 6-13 shows the sensitivity to this weight. It will be seen that for weights above 0.95 no action becomes preferred. This weight implies that the land is valued at about $20,000/acre ($133/tree) which is about five times the assessed value. For certain very highly desirable recreation sites, this may be a feasible value.

6.3 Recommendations for Action

In order to translate the results and sensitivity analyses described above, into implied recommendations for action, a full understanding of the strengths and weaknesses of our analysis is required. We now look at these recommendations, classified by land type and status.

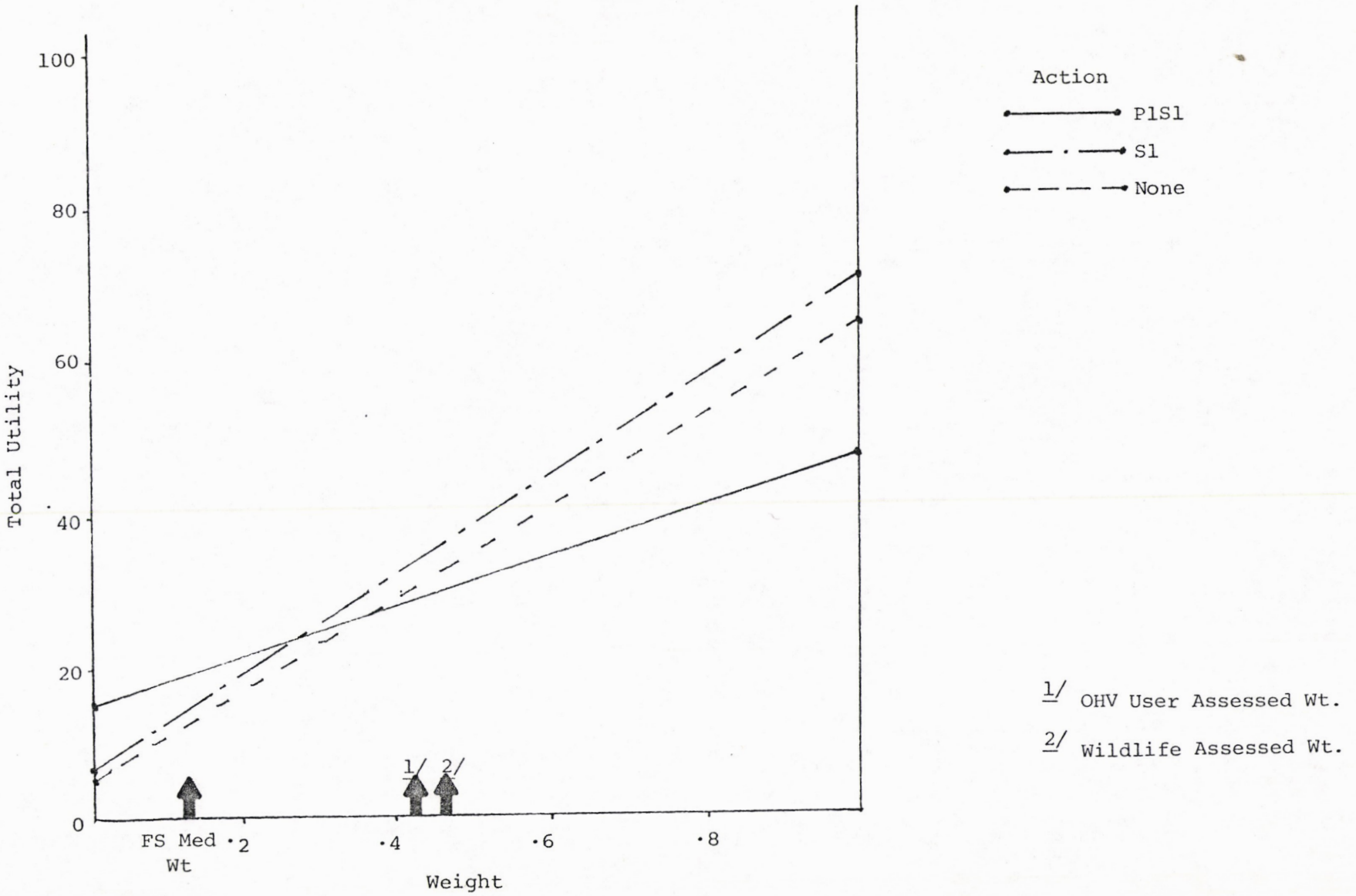


EXHIBIT 6-9

Sensitivity of FS Medium Evaluation to Weight on Recreation
Lands A - Mild or Heavy

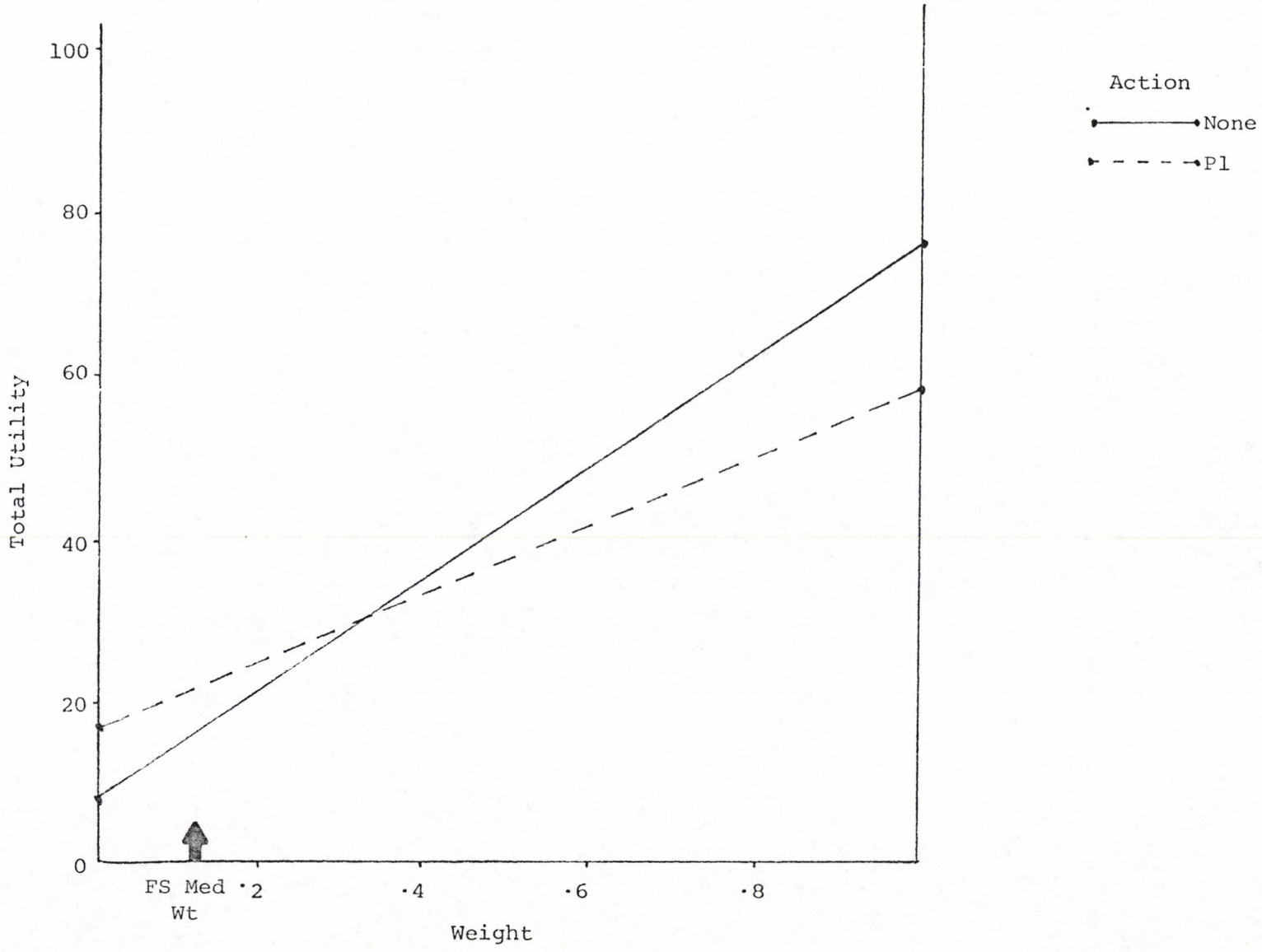


EXHIBIT 6-10

Sensitivity of FS Medium Evaluation to Weight on Recreation
Lands A - Stopped

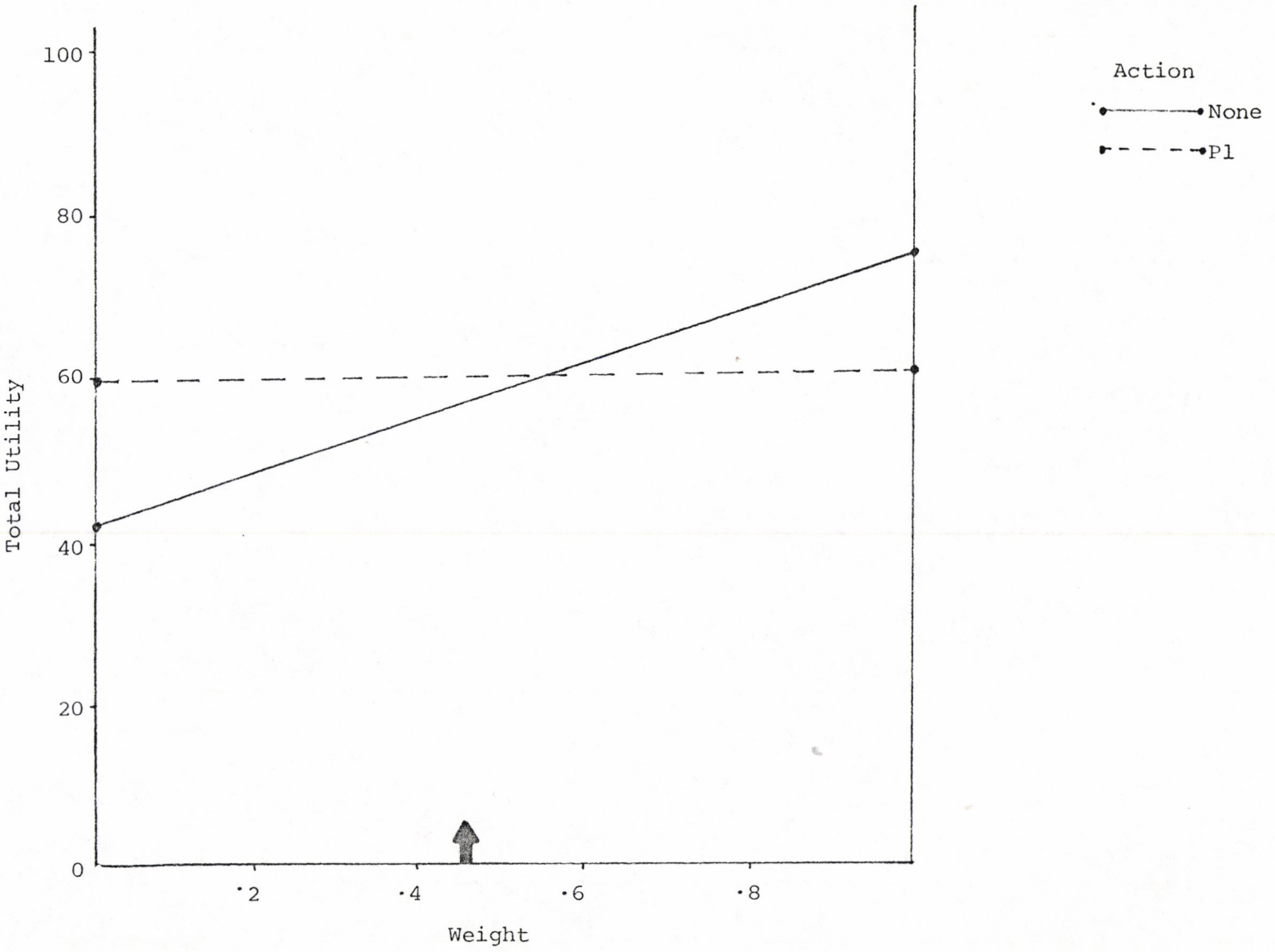


EXHIBIT 6-11

Sensitivity of Wildlife Constituency Evaluation to Weight on Recreation
Lands A - Stopped

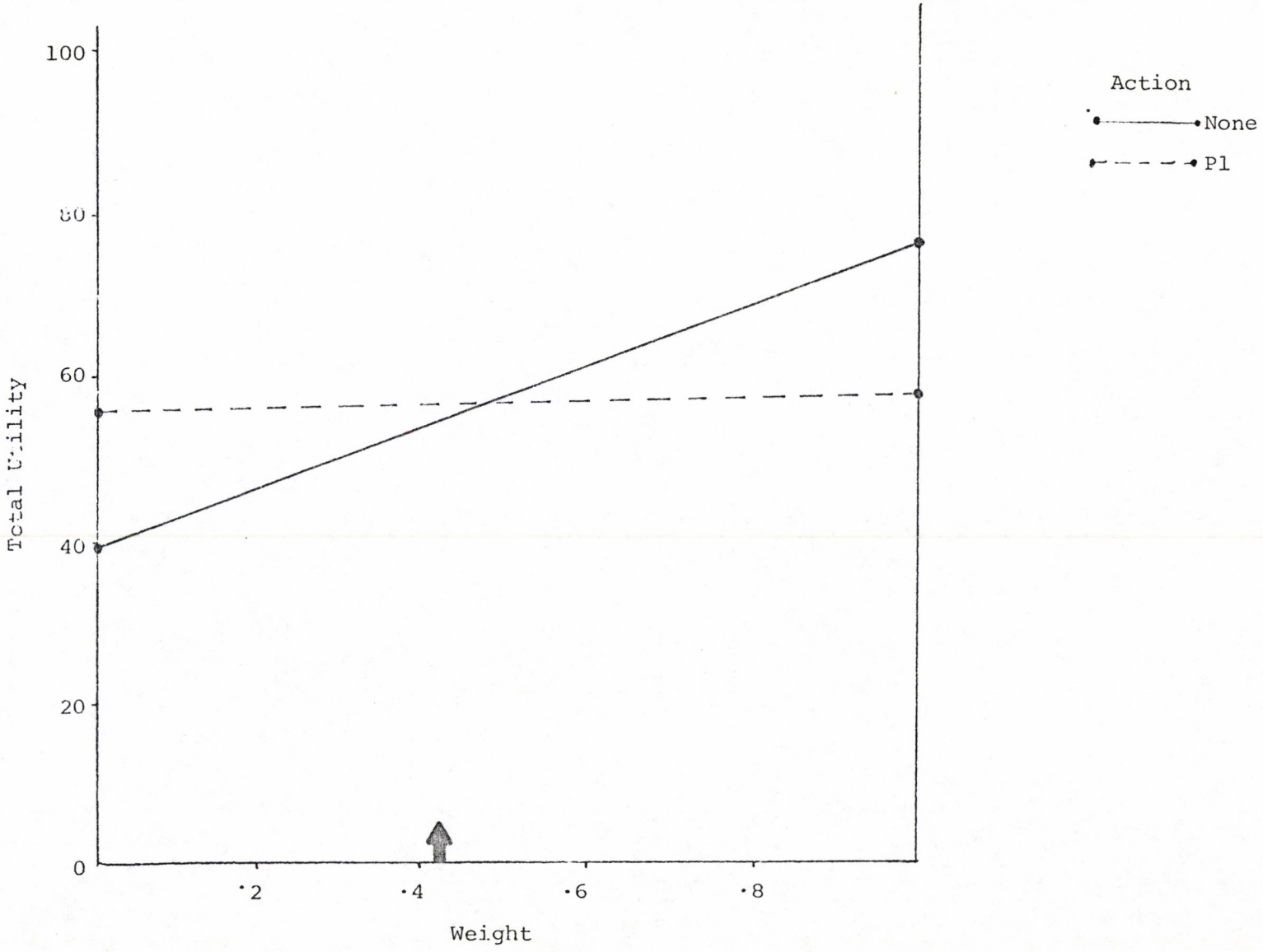


EXHIBIT 6-12

Sensitivity of OHV User Evaluation to Weight on Recreation
Lands A - Stopped

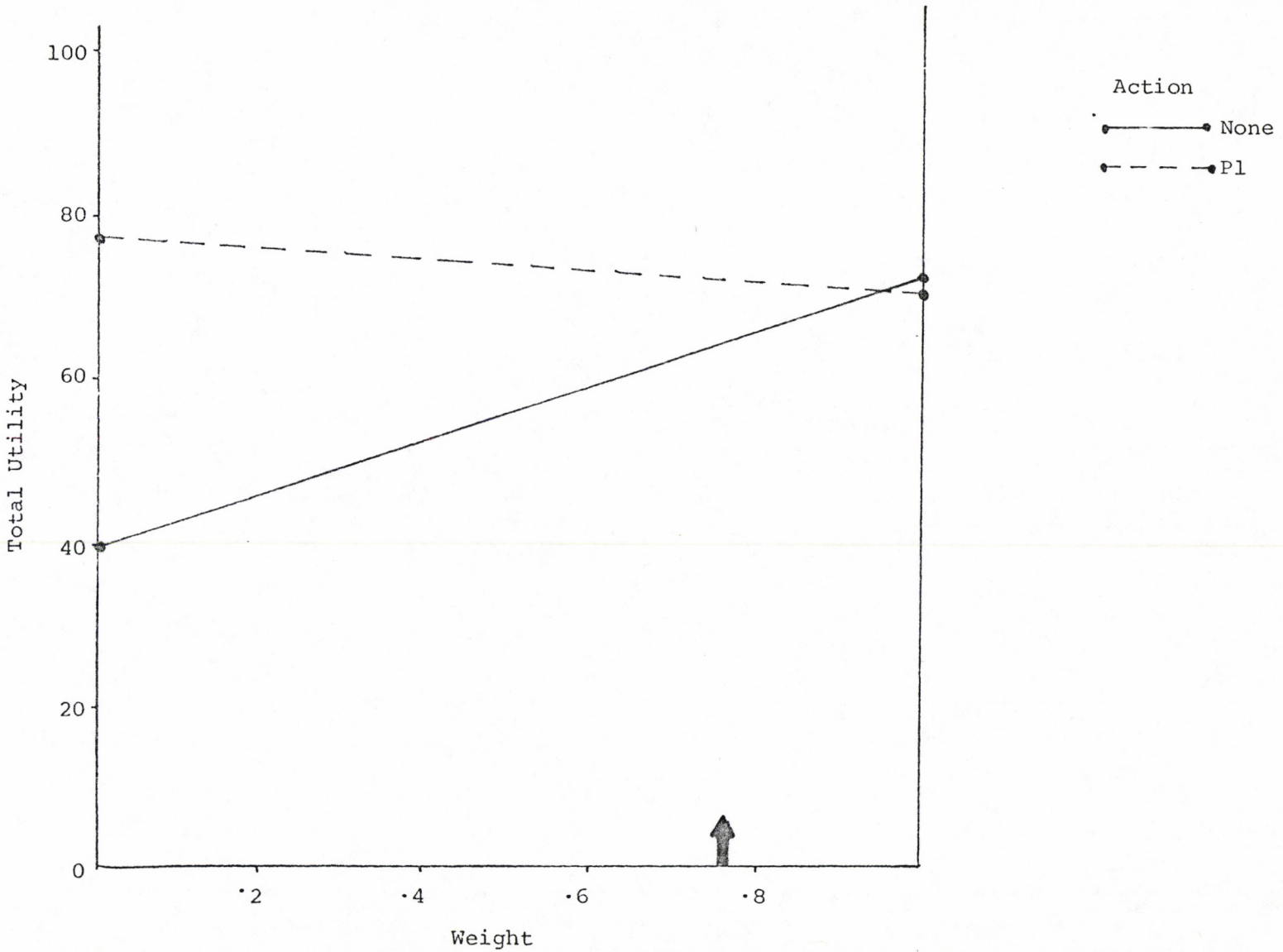


EXHIBIT 6-13

Sensitivity of FS High Evaluation to Weight Assigned to Recreation
Lands A - No Beetles

6.3.1 Lands A - mild or heavy epidemic. On the developed recreation sites, where values are quantified by the FS High constituency, suppression by harvesting of infected trees (S1) is clearly preferred. On the medium value lands there is an apparent disagreement between the Wildlife and OHV User groups, who prefer S1, and the Forest Service and the Sierra Club, who prefer thinning and harvesting (P1S1). As explained in Section 6.2, this disagreement arises from differences in the value placed on the land. The results for the Sierra Club are, however, in need of further interpretation.

The Sierra Club is a special case, since the non-monetary aspects are considered irrelevant to MPB treatment, and will thus always show a low value for land. However, we feel that our analysis has perhaps not appropriately captured Sierra Club interests, since their expressed beliefs imply a strong disutility for apparent interference in the environment by man, which we have not explicitly modeled. In fact, they would probably object strongly to thinning, and prefer suppression or doing nothing.

Since it appears that there is quite a major disagreement between the major interest groups on the one hand, and the Forest Service on the other, it might perhaps be best for the Forest Service to initiate suppression in these areas while committing the limited resources available for thinning to other, less contentious areas. These results also indicate the need for further, more detailed, research into quantifying the non-market value of the lands. A developed method would help in resolving the conflict exhibited at present between the Forest Service and public interest groups.

6.3.2 Lands A - stopped. On the developed recreation sites, the analysis shows that taking no action is generally preferred when the beetle is not present, the only exception being if the land is of extremely high value (about $50,000/acre) when chemical prevention becomes feasible. On the medium value stands, thinning is generally indicated. However, on those stands with somewhat more recreation value than the average, doing nothing is preferable. (Note that we recommend taking no action in stands where the beetles are not currently active. If and when a new epidemic starts, the stand comes under consideration as one in Lands A Medium or Heavy, when appropriate action is to be taken.)

6.3.3 Lands A - no beetles. On these lands thinning is strongly indicated as desirable, the tree loss due to the MPB may thus be avoided entirely. The only exception to this recommendation is for very high value areas where cutting down a tree would be a severe loss. As indicated in the sensitivity analysis, the stand would need to be valued at greater than $20,000/acre for this to be the case.

6.3.4 Lands B. On these low value high-susceptibility lands, the recommendation implied by our analysis is unequivocal; an extensive thinning program should be carried out.

6.3.5 Lands C - mild or heavy. On these lands, there was again some apparent disagreement between the Forest Service and the Sierra Club preferring no action, and Wildlife and OHV User interests preferring suppression. However, it is apparent that the preferences for no action are very slight, and as shown in the sensitivity analysis, the Forest Service preference shifts to suppression with a very small increase in its valuation of the land. It thus apprears that in order to be maximally responsive to public input, suppression should be initiated on such lands. (Since the Forest Service weights indicate virtual indifference between suppression and no action, little unease should be felt at this choice.)

6.3.6 Lands C - stopped. On these lands the recommendation to take no action is unequivocal.

6.3.7 Lands E - beetles. On these lands suppression is universally agreed to be worthwhile.

6.4 Prioritization of Work

Each of the actions recommended above provide desirable consequences, but funds may not be available to perform all work immediately, so the Forest Service needs some method of prioritizing the work. To help with this, we have used the results of our analysis to give an approximate indication of the dollar value to the Forest Service of undertaking the proposed action

in each case. This was done by using the weight on the cost criterion for the Forest Service to indicate the overall value of the land, as in Section 6.3, and then using this to determine the value of one unit, or utile, in our analysis as presented in Exhibit 6-1. The difference in utiles between the recommended action and no action could thus be converted into a dollar-equivalent. The results of this procedure are summarized in Exhibit 6-14.

We are now faced with a resource allocation problem, and it can be shown that the optimal strategy for the Forest Service is to put money into those types of land where the greatest benefit per acre is to be gained. Studying Exhibit 6-14 shows that the developed recreation sites and areas in Lands A without beetles should be treated as the highest priority, but that other medium value lands should not in general divert resources away from the extensive thinning program which is preferred in Lands B (which covers an area of over a million acres). This analysis should again be interpreted with common sense--in special cases good public relations will dictate that action should be taken in medium value areas where the public desires it. Also, consideration of the extent of a thinning program should take into account the amount of timber the Forest Service wishes to put on the market. The PQ3 Team estimated that the proposed management program would increase the supply of fuelwood and other forest products by 6.9 to 11.4 MMBF.

LAND TYPE, STATUS	PREFERRED ACTION	UTILITY OF PREFERRED ACTION	UTILITY OF NO ACTION	DIFFERENCE IN UTILITY	X	$ EQUIVALENT OF ONE UTILE	=	$ BENEFIT OF PREFERRED ACTION/ACRE
Lands A--Mild or Heavy Developed Recreation Sites	S1	44	40	4	X	60	=	240
Lands A--Mild or Heavy Medium Value Lands	S1[1/]	15	13	2	X	28	=	56
Lands A--Stopped Medium Value Lands	P1	21	17	4	X	28	=	112
Lands A--No Beetles Developed Recreation Sites	P1	72	66	6	X	40	=	240
Lands A--No Beetles Medium Value Lands	P1	67	45	22	X	9	=	198
Lands B	Thin	47	25	22	X	6	=	132
Lands C--Mild or Heavy Developed Recreation Sites	S2	29	26	3	X	45	=	135
Lands C--Mild or Heavy Medium Value Lands	S2[2/]	--	--	--		--		--
Lands E--Beetles Developed Recreation Sites	S1	91	74	17	X	30	=	510
Lands E--Beetles Medium Value Lands	S1	61	53	8	X	6	=	48

[1/] We use S1 as we anticipate this to be the preferred action (6.3)

[2/] As noted in 6.3, S2 is almost indifferent to doing nothing, and thus we assume has minimal benefit.

EXHIBIT 6-14

Dollar Benefits per Acre of Recommended Actions, from Forest Service Perspective

7.0 DISCUSSION OF ANALYSIS AND RESEARCH NEEDS

7.1 Discussion of Analysis Results

The results of the previous section clarify several aspects of the problem. First, chemical prevention clearly is not recommended except in extremely high value areas (and this holds true whether thinning is later carried out or not). This is largely because the effect only lasts for one year, after which time the stand returns to high-susceptibility. Really, P2 should be considered a form of suppression; as it is used with hope that the beetle will leave the area while the trees are protected, but expert opinion indicates that this hope is ill-founded.

Second, thinning is not such a universally good treatment as experts might have predicted. A major reason for this is that taking away trees has a detrimental effect. It should not be surprising that cutting down high-value trees in order to save them from the MPB is not viewed with total favor! The other major factor mitigating against thinning is that in areas where the beetle is already present, the Forest Service would be unable to prevent the first two years of beetle-kills, and since these first few trees provide most of the adverse impact, saving the remainder of trees by thinning is not so beneficial. In those high susceptibility areas where the beetle has not yet hit, however, thinning is far more attractive because those first few trees can be saved, whereas waiting for the beetle to arrive would be foolish. Thinning is recommended in lower value areas because there is little detrimental effect due to the thinning, so the silvicultural benefits become far more important.

A third general conclusion from the analysis is that, although suppression is usually effective only in slowing down an epidemic rather than reducing its effects, it is usually preferred to doing nothing--most especially in areas where S1, which is of negligible net cost, can be performed. Such a conclusion can be seen to arise largely due to the discounting procedure used. In the analysis, the difference between suppression and no action in moderate-to-high susceptible areas lies solely in the time when the trees dying,

actually die. With suppression the deaths are delayed and due to discounting, we consider these later deaths to have less of an adverse impact.

However, using an alternative plausible assumption we would find a different result. We have assumed that the adverse effect of red needles is proportional to the logarithm of the total number of trees killed. We could, instead, have assumed that the adverse effect for each year was proportional to the number of red needles in that year. It will be seen that these two assumptions are not equivalent, for suppression, which ensures a few trees killed for each of a greater number of years than the "no action" alternative, would, under the second assumption have a large adverse impact. This is because the few trees killed each year would still have a major impact each year, due to the logarithmic relationship. To make this point more clearly, we consider a hypothetical case.

Suppose 25% of the trees in an area are to die. With no action, suppose they would all die in year 1, whereas with suppression, 8% would die in each of the first two years, and 7% in the third. Under the assumption used in the analysis, the suppression option would be encoded as losing 25% of the trees in the second year (the average year of kill), and would thus be considered better than no action, due to discounting. Under the second assumption, because needles are red for two years following death, no action would have 25% of trees red for each of the first two years and none thereafter, whereas suppression would have 8% of trees red the first year, 15% the second year, 15% the third year and 7% the fourth year. Using the logarithmic relation, the score on a 0 to 100 scale for each action would be as follows:

	No Action	Suppression
Year 1	37	67
2	37	50
3	100	50
4	100	70

Then with both 5 percent and 10 percent discount rates, calculations show No Action to be preferred to suppression. The reason is clear--the public must endure substantial impacts for each of four years, and the greater severity for two years of taking no action is insufficient to counteract this.

The above discussion highlights a very important research need; at present the Forest Service has very poor information concerning the impacts of MPB kills on recreation and aesthetics. Until these effects are much better understood, the recommendations for suppression in Lands A and with beetles present should be considered with caution. This is a particularly intriguing problem, since if the second assumption proves to be correct, the optimal policy may prove to be to perform partial suppression, which is equivalent to performing suppression badly, or to having lack of cooperation. In such a case, the fact that some people refuse to cooperate may prove to be beneficial! At present, however, this remains a mere conjecture. It should be noted that the recommendation for suppression on Lands E is not subject to the same problem, since here the size of the epidemic is actually reduced. Similarly, the thinning recommendations do not depend on the assumption. The research need, however, is clearly very great.

Further research needs were identified during the course of the project, and we shall soon discuss these, but first we provide an example to show how a quantitative assessment of research needs can be gained using decision-analytic methodology.

7.2 Value of Information

The decision-analytic technique of Value of Information (VOI, see Appendix A) is a formally appropriate technique for assessing how much money is worthwhile putting into a certain kind of research. We were unable to conduct full VOI analysis during this study so we give an example in this section of how the methodology works in practice. The example is derived from our study, and hence is a real one, but the numbers are only approximate and so should be viewed as illustrative and indicative, rather than authoritative.

We consider the problem of mild or heavy epidemics. In the analysis we captured the present state of knowledge by assuming that we could not tell in advance whether a developing epidemic would be of the mild or of the heavy variety. However, it seems reasonable that the type of epidemic could be predicted in advance given greater knowledge, and the Forest Service may be interested in knowing how much money is worth spending to research this topic. It is thus faced with the additional decision on whether to perform such research. Exhibit 7-1 shows the expanded decision problem for the developed recreation sites in Lands A, including the initial decision on whether to perform the research project. If the study is not performed, the expected utility of the decision is 44, performing S1 as in Section 6.0 (The "No Study" branch). If the study is performed and shows the case under consideration to be susceptible to a mild epidemic (probability 0.94), then assuming prediction to be perfect, suppression would be performed (utility=46). If a heavy epidemic is predicted, thinning would be performed (utility=35). Therefore, the expected utility after performing the study is 0.94 x 46 + 0.06 x 35 = 45.34. The difference between the expected utilities on such land from performing the study is 1.34--the expected utility of perfect information (EUPI).

In reality, we know that we cannot obtain perfect information: no study could provide perfectly valid results. We could further investigate the utility of imperfect information by varying the probabilities of "heavy" given a predicted "heavy" and "mild" given a prediction of mild. However, perfect information provides a useful upper bound on the utility of information. This is particularly true if we translate utility into costs. For example, we can determine what the Forest Service would feel is the maximum they should pay for this type of information.

In order to calculate the expected value of perfect information we must translate utilities into costs. This is done using the weight for costs and the range of costs corresponding to the difference of the costs equal to zero and to 100 on the cost scale, as in Section 6.0. We find that the cost equivalent of one utility point is $60/acre. Multiplying this by the

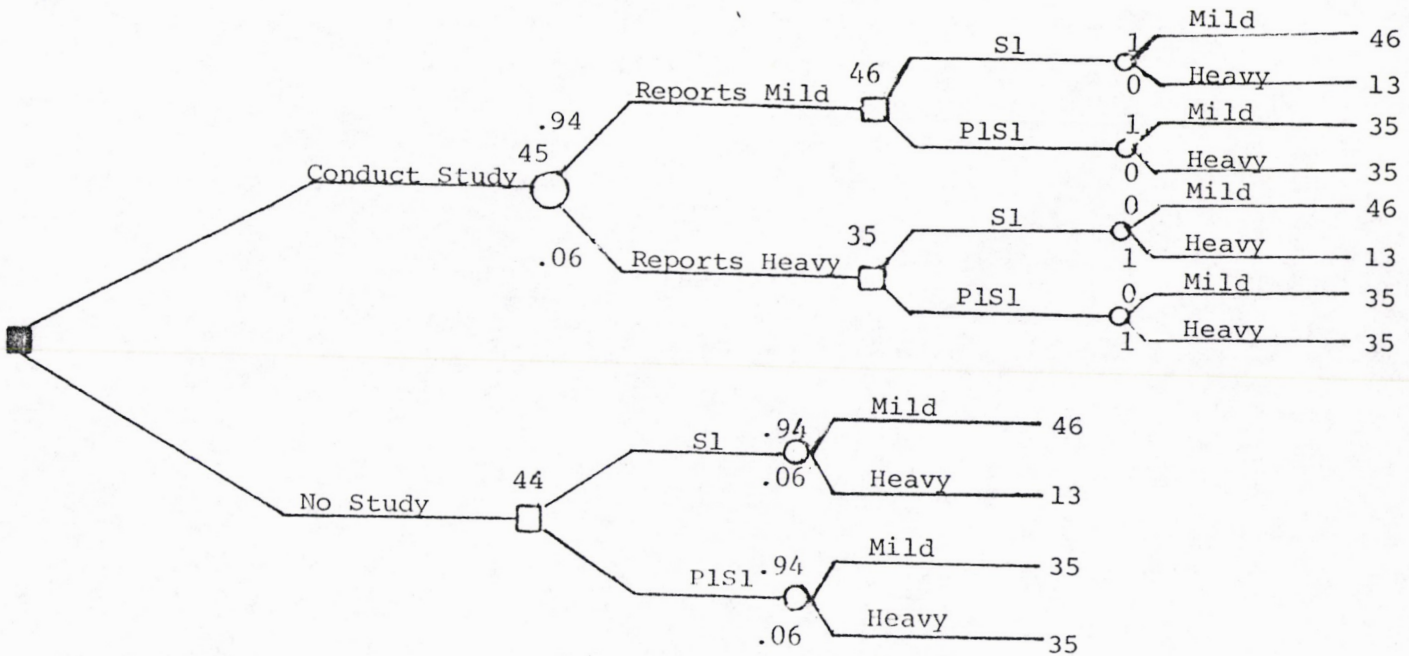


EXHIBIT 7-1

Expanded Decision Tree Including Information Acquisition Decision

1.34 expected utility of perfect information gives an expected value of perfect information of about $80/acre. Using the estimate in Exhibit 2-1 of 29,100 acres of such land, of which 72½% will be "mild or heavy" (= 21,100 acres), we find that the perfect research has an expected value over the region of about $1.7 million. There is also a potential benefit on Lands A - medium value, and Land C, high or medium value. Similar calculations show the overall values on such lands to be approximately $2.1 million, showing a total benefit of about $3.8 million. Under these conditions, the Forest Service would consider this an absolute upper bound on what they should pay for such research. The expected value of actual information would depend, of course, on the validity of the predictions that could be made on the basis of the research. As warned before, the above figures are mainly intended as an example, and should not be taken too seriously, but apart from the exemplification of the potential usefulness of the VOI methodology, they do indicate the potentially high stakes of performing further research on susceptibility.

7.3 Other Identified Research Needs and Weaknesses in the Analysis

In the course of the analysis we identified several areas in which further research was needed, and points on which we were forced to make questionable assumptions. In this section we look at the research needs and the weaknesses and discuss their importance.

As mentioned previously, there is a need for further research into the non-commodity impacts of Mountain Pine Beetle, and into the non-market values of lands in general. The techniques of multiattribute utility theory discussed in this report may help in quantification. One aspect of this value which we have ignored during our analysis is wildlife-related. Falling trees, and thinning areas will have an impact on wildlife habitat; for example clearing snags, which is an effect of a mild MPB epidemic, is beneficial for animals such as elk. In general we do not feel that the wildlife considerations would change the recommendations of the analysis, but feel that research should also be conducted in this area. Similarly the effects of fire should be better understood, both in general, and on wildlife in particular.

As indicated by the VOI example, a second general area of necessary research is in risk-rating of stands. Not only is there a research need in distinguishing between mild and heavy epidemic areas, but also the present state of knowledge of risk-rating of stands is poor. It appears that an improved definition of high- and low-susceptibility is necessary in order to gain the full benefits of our analysis, and that the development of such a risk-rating scheme is an area of research in which immediate benefits could be reaped. Related to this is further research on the effects of silvicultural practices such as thinning on susceptibility to Mountain Pine Beetle. The assumption that thinning reduces high susceptibility to low susceptibility is adequate and seems realistic, but as further research refines definition of susceptibility, so should the knowledge concerning the precise consequences of thinning be increased.

A caution concerning a possible weakness in our analysis regarding the perceived effect of a heavy epidemic is in order. We have quantified this by saying that all tree-related value of a land is removed. This is true, but it is also true that the adverse effect will last longer than the twenty-year time horizon, and hence that the effect of a heavy epidemic may be still greater than we have assumed. Further research is needed on the effect of such a "clear-cut," but due to the low probability of such an epidemic, we do not believe the recommendations would be significantly altered.

8.0 REFERENCES

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Seaver, D. A., and Freeling, A. N. S. Decision analysis in Forest Service planning: Roads, trails, and utility corridors (Technical Report 80-7). Falls Church, VA: Decision Science Consortium, Inc., 1980.

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APPENDIX A

OVERVIEW OF DECISION ANALYSIS

In general, decision analysis (see e.g., Brown, Kahr and Peterson, 1974; Raiffa, 1968) provides for the evaluation of alternatives, focusing on the values or utilities associated with outcomes and the probabilities of those outcomes. A complex problem is decomposed or analyzed into clearly defined components, such as alternatives, uncertainties, and values. The uncertainty and value components are quantified using whatever information and expertise are available.. Logical implications of the analysis (for action, assessment, or prediction) are deduced, displayed, and incorporated into the decision making process.

In the formal model the value and the probability of each of the possible outcomes occurring as the result of selecting a particular alternative are determined. The overall value of the alternative is then obtained by weighting the value of each outcome by its probability and summing across all possible outcomes. The overall values of the alternatives under consideration can then be compared. In practice, decision analysis is often used less formally as an aid to the decision making process.

Several individuals or groups may become involved, especially if they differ in their expertise regarding different problem components. In addition, decision makers--whether individuals or groups--can use decision analysis to discipline their informal reasoning, and to facilitate communications among individuals in command structures, committees, or various interest groups. For example, decision analysis can be used to communicate the grounds for a recommendation, to identify sources of disagreement, to focus different expertise on appropriate parts of a problem, and to determine the critically important aspects of a complex decision problem.

Raiffa (1974) has briefly characterized decision analysis as follows:

> The decision analytic approach defines a procedure by which a decision maker can make reasoned choices that will be consistent with his perceptions about the uncertainties involved in a par-

ticular problem, together with his fundamental attitudes toward risk taking. Decision analysis pays particular attention to:

- a decision maker's judgments about the uncertainties in his problem
- the use of information supplied by expert advisors
- the decision maker's feelings about consequences that may result from his choice of action
- the decision maker's basic attitudes toward value tradeoffs and risk taking
- opportunities to acquire relevant information (possibly through experimentation) before arriving at a final decision, considered in the light of the cost of obtaining such information. (p. 3)

An important and distinctive aspect of decision-analytic approaches pertains to how judgment enters into an analysis. Many non-decision-analytic approaches try to ignore judgmental input altogether, seeking a spurious form of objectivity. Other approaches recognize that the judgments and opinions of the decision maker are valid inputs, but treat them in an informal fashion. Decision analysis is distinctive in part because it involves the careful quantification of both values (using utility theory) and uncertainty (using personal probability theory). It explicitly introduces such subjective quantities into the analysis rather than analyzing only "objective" components. The theoretical basis underlying this use of subjectivity is well-developed, and practical applications are becoming extensive.

Decision analysis, however, does not rely solely on judgmental input. A unique feature of many decision-analytic tools is their capability to use either objective or subjective inputs, and more specifically their capability to combine both types of inputs when both are available. That is, decision-analytic models can utilize the best information available bearing on the problem at hand, regardless of the exact type or form of information.

Decision analysis is a complete and comprehensive approach to decision problems based on a logically consistent and complementary set of theoretical concepts

and analytic techniques. Below we discuss these basic concepts and some of the techniques used in our analysis of Planning Question 8.

A.1 Underlying Concepts

The major components of a decision-analytic model are the options or alternatives among which a decision is to be made, the uncertain events which determine the outcomes of the alternatives together with the likelihood of each event, and the values or utilities associated with these outcomes. Thus, the basic concepts on which decision analysis is founded are the structuring of the problem which develops the relationships among the components, probability theory (particularly personal probability theory) which provides a means for measuring uncertainty, and utility theory (particularly multiattribute utility theory) which is the basis for measuring values.

A.1.1 Structuring the decision problem. The initial, and perhaps the critical, task in addressing a problem using decision analysis is structuring the problem. To a large extent structuring is an art rather than a theoretically based, well defined methodology. Successful structuring usually depends on the expertise and experience of the decision analyst and the creativity, expertise, and cooperation of the decision maker(s) and other relevant substantive experts.

A critical aspect of structuring is identifying and developing the decision alternatives or options to be analyzed. This is not a one-shot process, but rather one that is likely to be iterative as the analysis proceeds. Intermediate analysis results may well suggest modifications in alternatives already under consideration, or completely new alternatives to be analyzed.

In complex problems of the type addressed in the regional planning questions, alternatives will often consist of different mixes of components. For example, in Planning Question 8, the alternatives available to the Forest Service consist, in part, of different mixes of uses for various miles of roads and trails.

In addition to alternative identification, the other major aspects of structuring are the identification of key uncertainties, of the relevant criteria for evaluating the outcomes of the various alternatives, and of the interrelationship among uncertainties and among criteria. Typically in decision analysis, the problem is structured using a decision tree. Exhibit A-1 illustrates a simple decision tree for a decision regarding whether to buy a new house now or wait six months. The outcome of this decision depends upon uncertain events: what happens to the mortgage interest rate, and to the general cost of housing. The relevant criteria for evaluating outcomes are, in this case, the costs of both the house and the mortgage interest, tax breaks, and the pleasure of living in a new home. Depending on the path through the tree, different outcomes will be obtained. By assigning probabilities to the uncertain events (i.e., to p, q, and q') and utilities to the outcomes, the overall expected utility of each alternative can be calculated. The mathematical foundation of decision theory shows this to be the sum across all possible outcomes of the utility of the outcome multiplied by its probability. The following sections discuss the concepts which are used to assign probabilities and values.

A.1.2 Personal probability theory. Because, in part, Forest Service planning involves consideration of uncertainty in the future, existing objective data, based only on the past and present, may relate only indirectly to critical uncertainties. Thus, as in most planning, expert judgment is often the best available information concerning the likelihood of uncertain events. Probability theory in general, particularly personal probability theory (cf. Savage, 1954) provides a formal mechanism for quantifying uncertainty in a manner consistent with the principles of rational decision making.

In many instances, some data will be available that provide information on the likelihood of uncertain events occurring. The data, however, may be insufficient to provide an accurate probability assessment. Therefore, it may be desirable to augment the information from the data with expert judgment.

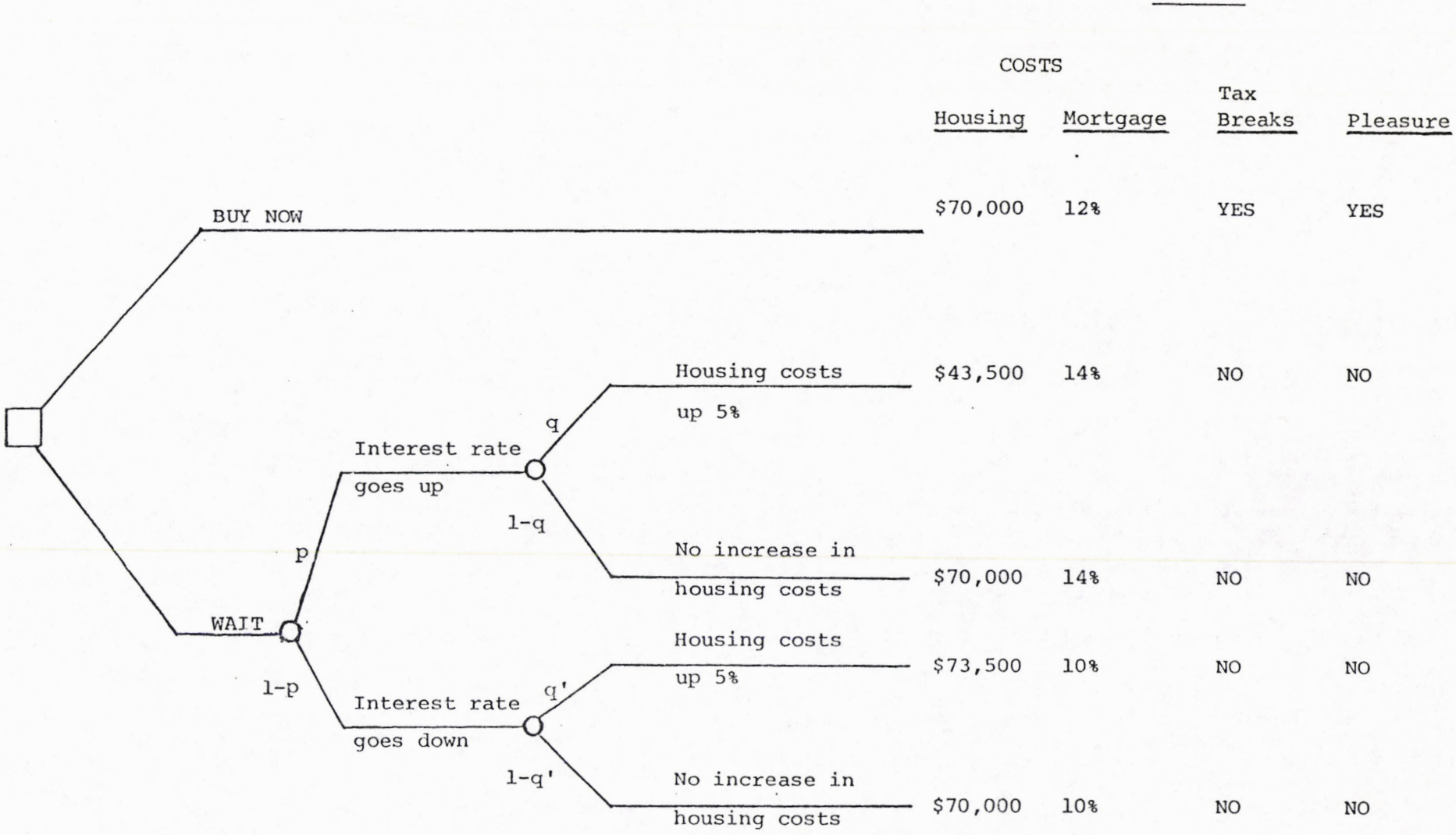

EXHIBIT A-1

Typical Decision Tree

Probability theory also provides a formal mechanism for establishing the relationship among uncertain events, through conditional probabilities. For example, in Exhibit A-1, the probabilities q and q' of 5% cost increases are conditioned on whether the interest rate goes up or down. Since both cost and interest rates are to some extent related to the general underlying economic situation, they are likely not to be probabilistically independent. That is, q and q' may well be different probabilities. Use of conditional probabilities not only shows these relationships, but also may make the required probability assessments judgmentally easier, since each assessment is more specific.

A.1.3 Multiattribute utility theory. The multiobjective nature of Forest Service planning suggests the relevance of multiattribute utility (MAU) theory as an evaluation methodology. The application of MAU theory provides a theoretically justified procedure for assigning value to alternatives that have multidimensional effects and for explicitly reflecting the relative importance of each effect, and, therefore, the tradeoffs among them.

The use of MAU theory begins with the specification of the alternatives that are to be evaluated. Then, the "attributes," or objectives, that are to be used to evaluate alternatives are delineated. Each alternative must then be "scored" on each attribute. This scoring can be accomplished by different means. Attributes that have underlying quantitative measures, e.g., cost and timber production, can be scored using a single-attribute utility function. Such functions relate the underlying measure to value. Often a simple linear function will suffice as an excellent approximation provided the relationship between the underlying measure and value is monotonic, i.e., value always increases (or decreases) as the measure increases. This will generally be true for costs, for example. More complex procedures may be required, however, to establish single-attribute utility functions for other attributes.

Scoring on attributes that do not have underlying quantitative measures is done by direct expert judgment. This entails establishing a scale with well-

defined upper and lower endpoints and asking the experts to rate the alternatives on this scale. This approach would generally be used to score aesthetic and cultural effects.

The scoring of alternatives on an attribute-by-attribute basis described in the preceding discussion is formally appropriate only if some assumptions with respect to the independence of attributes are satisfied. (Keeney and Raiffa (1976) provide the technical details of these assumptions.) However, users of MAU models can generally be assured that such a decomposed scoring procedure is satisfactory if the scores (i.e., the relative values) assigned to one attribute do not depend on the level of the other attributes. For example, if two alternatives produce the same effect on timber production, their scores on the timber production attribute should be the same regardless of the fact that they have different costs.

The next step in the development of a MAU model is the specification of weights for each attribute. The interpretation of weights and the procedure for assessing them depends on the form of the model to be employed to aggregate the single-attribute scores. The theoretical basis for a variety of aggregation models has been developed (see Keeney and Raiffa, 1976), but in Planning Question 8 an additive aggregation rule was appropriate, so that is our focus here.

Weights are assessed by considering the relative importance of moving from the worst to the best level on each attribute. The assessments are ratio judgments, meaning that if the importance of going from worst to best on one attribute is twice that of another attribute, the first attribute is assigned a weight twice that of the second. This assignment of weights on the basis of "swings" from worst to best is an important feature reflecting the theoretical basis of MAU that differentiates it from weighting procedures based on some ill-defined concept of "importance." These ratio judgments are then normalized to sum to one to facilitate further calculations.

The overall value of an outcome of a particular alternative can then be computed by summing the single attribute scores weighted by the normalized weights across all attributes. If there is no uncertainty about what the outcome of an alternative will be (or if the uncertainty is not formally incorporated into the evaluation), this overall value represents the relative value of the alternative. If uncertainty about outcomes is explicitly modeled, the value of each outcome must be weighted by its probability and summed across outcomes to provide an overall value measure for the alternative.

A.2 Some Specialized Techniques and Uses

The above discussion outlines the general concepts on which decision analysis is based, and some of the formal procedures that may be utilized. But additional decision-analytic tools may be relevant to specific problems, and experience suggests some ways in which decision analysis can be used particularly effectively in Forest Service planning. In this section we describe some of these specialized techniques and uses. We focus primarily on those that may be most valuable in Forest Service planning, although we include brief descriptions of techniques that would only be useful in very special instances.

A.2.1 Value of information. A special kind of decision-analytic technique has been developed and successfully applied to problems concerned with deciding how much and what kind of information to collect and use. These information decisions differ from what are called primary decisions in that primary decisions lead directly to some outcome, whereas information decisions lead to the gathering or analysis of data prior to making subsequent decisions.

The decision-analytic approach to informational decisions or evaluations is based upon the realization that the value to be attributed to any information ultimately derives from the likelihood that the information in question will cause later decisions to be changed in such a way as to increase the chances of a desirable outcome. If the expected improvement in the expected benefit of primary decisions exceeds the expected cost of the information collection and processing, then that difference is a measure of the net expected value of the information.

The concept of value of information can often be used informally and qualitatively within a decision-analytically structured problem rather than as part of a fully quantified analysis. Planners can make informed judgments as to what information might have a real impact on the evaluation of alternatives and what the cost of such information might be. Simply considering this problem in a structured although qualitative manner may help identify some particularly valuable information.

Value of information can also be used as a resource allocation tool. Planners will never have unlimited resources available for planning. An early preliminary analysis of the alternatives used in conjunction with the concepts of value of information can help direct resources toward the areas where information and analysis will most significantly improve the evaluation and decision process.

A.2.2 Multiconstituency analysis. One of the more difficult tasks facing Forest Service planners is the balancing of the priorities and preferences of different individuals and interest groups (constituencies) affected by or interested in the planning. Which alternative appears to maximize the achievement of objectives will depend on the tradeoffs among objectives and the preferences of constituencies will be reflected in different tradeoffs. The techniques of decision analysis may offer planners some assistance in considering multiple constituencies and their preferences.

Several approaches might be taken. One, the most complicated, is to use multiattribute utility theory as a negotiation technique (e.g., Barclay and Peterson, 1976). By examining through multiattribute utility methods, the preferences of different constituencies, alternatives may be identified that increase the utility for some or all constituencies without any reduction for others. This type of negotiation process focuses on tradeoffs across objectives (and subcomponents) rather than on component by component negotiations. The planner can play a role akin to that of a mediator to attempt to maximize the utility accruing to the various constituencies within an equitable framework.

A second approach to the multiconstituency problem is to assign weights to the various constituencies. Although this is probably unacceptable politically

if used to provide definitive recommendations, it can be used as a planning and decision making aid. In particular, using sensitivity analysis, ranges of weights within which the choice of alternatives does not change may be determined. If the choice changes only when the weight or weights assigned to a certain constituency or constituencies fall outside a reasonable range, the balancing of constituency interests may be relatively easy.

Even when no such easy solution is available, the explicit representation of the preferences and priorities of the multiple constituencies with multi-attribute utility models can be a valuable approach. This decomposition will indicate the particular areas of disagreement and focus attention directly on them rather than on the overall choice of alternatives. Often constituencies will find that by considering the entire range of impacts within the multi-attribute framework, there is less disagreement than when alternatives are compared holistically (Gardiner and Edwards, 1975).

This explicit representation can also assist in the normal political decision making process. By communicating to decision makers with directly comparable information, the value of alternative plans from the perspective of the various constituencies, planners fulfill their own mandate and do so in a manner consistent with the needs of other decision makers.

A.2.3 Sensitivity analysis. Limited resources and fallible measurement techniques will make any Forest Service planning exercise imperfect. By utilizing a decision-analytic framework for planning and carefully conducted sensitivity analyses, the effects of the imperfections can be studied.

Often sensitivity analysis can be used to determine whether or not more extensive planning is needed. Varying uncertain parameters through their range of possibility will assist in determining whether or not the uncertainty should be considered explicitly through probabilistic analysis and will provide guidance in an informal manner as to the value of collecting additional information.

One of the more useful ways in which sensitivity analysis can be employed is in varying the weights assigned to attributes in a MAU model. These weights are judgmental, and as such are subject to some error. Although assigning an exact weight may be somewhat difficult, often a range of values may be determined with considerable confidence. Sensitivity analysis may then be used to explore whether or not variation within the range affects the overall evaluation of alternatives.

Sensitivity analyses also have a practical use when considering multiple consitituencies. Varying weights assigned to constituencies will provide insight into how to balance different interests. Sensitivity analysis may also show just how critical differences in the weights constituencies assign to attributes may be. This can be accomplished by varying the weight of any attribute across the range of weights assigned by the various constituencies. If this variation does not really change the overall evaluation of alternatives, the differences may be relatively unimportant.